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15th International Free Electron Laser Conference

free electron laser

1993

BOOK OF ABSTRACTS

Organisation:

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The Conference is organised jointly by the FOM Institute for Plasma Physics in Nieuwegein and the Department of Applied Physics of the University of Twente in Enschede.

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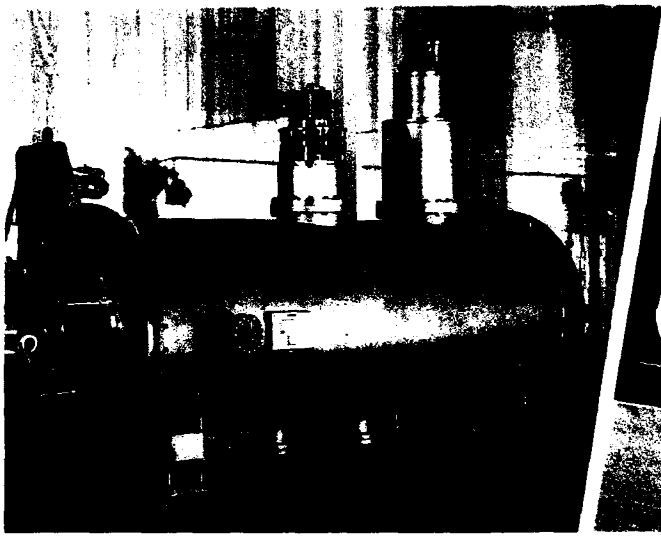
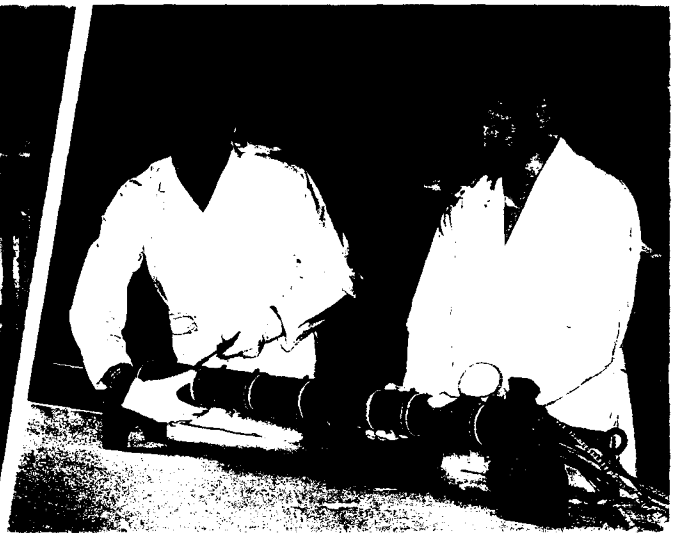


Superconducting accelerator module for the JAERI FEL experiment Japan



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Conference Programme

Sunday

Registration

16:00		**Registration and Informal get-to-gether**

Monday

Registration

8:00		**Registration**

Session : Opening

9:00	Mo1-1	**Welcome:** - Dr. P.A.J. Tindemans Director Research and Science Policy Ministry of Education and Science - Ir. N.A.M. Hootsmans *Managing Director* Ultra-Centrifuge Nederland N.V.
9:20	Mo1-2	**FEL Prize Lecture:** **FEL Technology Through the Eyes of a Power Tube Engineer** R.M. Phillips SLAC, U.S.A.
10:00	Mo1-3	**Initial Performance of Los Alamos Advanced Free Electron Laser** D.C. Nguyen, R.H. Austin, K.C.D. Chan, C.M. Fortgang, W.J.D. Johnson, S.M. Glerman, J.M. Kinross-Wright, S.H. Kong, K.L. Meier, J.G. Plato, S.J. Russel, R.L. Sheffield, B.A. Sherwood, C.A. Timmer, R.W. Warren, M.E. Weber LANL Los Alamos, U.S.A.
10:20	Mo1-4	**First Observation of Amplification of Spontaneous Emission Achieved with the Darmstadt IR FEL** J. Auerhammer, H. Genz, H.-D. Gräf, W. Grill, R. Hahn, A. Richter, V. Schlott, F. Thomas, J. Töpper, H. Weise, T. Wesp, M. Wiencken Techn. Hochschule Darmstadt, Germany
10:40	*Coffee break*	

	Session : Experimental Results 1	*Chairman : T.C. Marshall*
11:10	Mo2-1	**Performance and Tuning Characteristics of the ENEA Compact FEL** F. Ciocci, A. Doria, G.P. Gallerano, E. Giovenale, M.F. Kimmitt, G. Messina, W.B. Case ENEA Frascati, Italy
11:30	Mo2-2	**A Millimeter-range FEL Experiment Using the Coherent Synchrotron Radiation Emitted From Electron Bunches** M. Asakawa, N. Sakamoto, N. Inoue, T. Yamamoto, K. Mima, S. Nakai, J. Chen, M. Fujita, K. Imasaki, C. Yamanaka, N. Ohigashi, T. Agari, T. Asakuma, Y. Tsunawaki ILE, Osaka University, Japan
11:50	Mo2-3	**Demonstration of Ultraviolet Lasing with a Low-Energy Electron Beam** P.G. O'Shea, S.C. Bender, D.A. Byrd, B.E. Carlsten, J.W. Early, D.W. Feldman, C.M. Fortgang, J.C. Goldstein, B.E. Newnam, M.J. Schmitt, R.L. Sheffield, R.W. Warren, M.D. Wilke, T.J. Zaugg LANL Los Alamos, U.S.A.
12:10	Mo2-4	**Experiments with Grating-Coupled Free-Electron Lasers** J.E. Walsh Dartmouth College, U.S.A.
12:40	*Lunch*	

	Session : Poster 1	
14:00	Mo3-01	**Commissioning for the JAERI FEL Superconducting Accelerator Modules and Cryogenic System** E.J. Minehara, N. Kikuzawa, R. Nagai, M. Sawamura, M. Takao, M. Sugimoto, M. Ohkubo, J. Sasabe, Y. Suzuki, Y. Kawarasaki FEL Lab. JAERI , Japan
	Mo3-03	**Study of Undulator Influence on the Dynamic Aperture for the Duke FEL Storage Ring** Y. Wu, V.N. Litvinenko, J.M.J. Madey Duke University, U.S.A.
	Mo3-05	**Performance of a MOPA Lasersystem for Photocathode Research** R.F.X.A.M. Mols, G.J. Ernst University of Twente, The Netherlands
	Mo3-07	**Numerical Investigation of a Laser Gun Injector at CEBAF** S.V. Benson, J.J. Bisognano, P. Liger, H.X. Liu, G.R. Neil, D.V. Neuffer, C.K. Sinclair, B. Yunn CEBAF , U.S.A.

14:00 Mo3-09 **Dynamic Cavity Desynchronisation in FELIX**
G.M.H. Knippels, R.J. Bakker, A.F.G. van der Meer, D.A. Jaroszynski, D. Oepts, P.W. van Amersfoort
FOM Rijnhuizen, The Netherlands

Mo3-11 **Amplification of Spontaneous Emission with Two High-Brightness Electron Lunches of the ISIR Linac**
S. Okuda, J. Ohkuma, S. Suemine, S. Ishida, T. Yamamoto, T. Okada, S. Takeda
ISIR, Osaka University, Japan

Mo3-13 **Investigation of Microwave FEL with Reversed Guide Field**
A.A. Kaminsky, A.K. Kaminsky, V.P. Sarantsev, S.N. Sedykh, A.P. Sergeev, A.A. Silivra
JINR, Russia

Mo3-15 **Slippage, Noise and Superradiant Effects in the UCLA 10 μm FEL Experiment**
P. Pierini, R. Bonifacio, C. Pellegrini, J. Rosenzweig, G. Travish
INFN Milan, Italy

Mo3-17 **Design of a Hybrid Free-Electron Laser Amplifier**
K. Saito, S. Hiramatsu, K. Takayama
KEK Japan, Japan

Mo3-19 **A FEM Section with Selective Feedback on the Basis of an External Resonator with an Echelette**
V.A. Bogachenkov
Lebedev Institute, Russia

Mo3-21 **Microwiggler Generated on the Surface of PZT[Pb<Zr,Ti>03] Acoustic Waveguide using High Power Ultrasonic Waves**
J.S. Choi, C.H. So, H.T. Chung, D.R. Kim
Dongshin University, Korea

Mo3-23 **Two Color FEL Complex Based on High Current Race-Track Microtron**
E.B. Gaskevich, A.I. Karev, V.G. Kurakin
Lebedev Institute, Russia

Mo3-25 **A Free Electron Laser with Ion-Focussed Double Undulator for VUV and X-ray Generation**
A.V. Tulupov
FOM Rijnhuizen, The Netherlands

Mo3-27 **Status of the UCSB Free-Electron Lasers**
G. Ramian
UCSB, California, U.S.A.

14:00 Mo3-29 **Progress of the FELICITA I Experiment at DELTA**
D. Nölle, A. Geisler, M. Ridder, T. Schmidt, K. Wille
University of Dortmund, Germany

Mo3-31 **Status of the Commissioning of the SC Linac LISA for the 'SURF' FEL Experiment**
M. Castellano, M. Ferrario, M. Minestrini, P. Patteri, F. Tazzioli, N. Cavallo, F. Cevenini, F. Ciocci, G. Dattoli, A. DiPace, G.P. Gallerano, A. Renieri, E. Sabia, A. Torre, L. Catani
INFN Frascati, Italy

Mo3-33 **Two Frequency Wiggler FEL Oscillator: Sideband Inhibition and Efficiency Enhancement**
P. Chaix, D. Iracane, A. Bourdier
CEA/PTN, France

Mo3-35 **Closure Relations in Macroscopic FEL Equations**
G.H.C. van Werkhoven, T.J. Schep
FOM Rijnhuizen, The Netherlands

Mo3-37 **Computer Simulation of Mode Evolution in Long Pulse FELs**
I. Kimel, L.R. Elias
CREOL-Univ. Central Florida, U.S.A.

Mo3-39 **Chaotic Electron Trajectories in a Helical-Wiggler Free Electron Laser**
A. Bourdier, L. Michel-Lours
CEA/PTN, France

Mo3-41 **Investigation of Multifrequency Generation in the FEM**
P.J. Eecen, A.V. Tulupov, T.J. Schep
FOM Rijnhuizen, The Netherlands

Mo3-43 **Quasi-optical Theory of the FEL Oscillator with Cylindrical Mirrors**
V.A. Balakirev, V.V. Ognivenko
Kharkov Institute, Ukraine

Mo3-45 **Preiiminary Considerations of a Free Electron Laser Operating at Very Large μc**
V.I. Zhulin, R.J. Bakker, A.F.G. van der Meer, D. Oepts, P.W. van Amersfoort
FOM Rijnhuizen, The Netherlands

Mo3-47 **FELICITA II: A Possible High-Gain FEL at the Storage Ring DELTA**
M. Ridder
University of Dortmund, Germany

14:00 Mo3-49 **Gain Enhancement in Gas-Loaded FEL**
L.A. Gevorgian
Yerevan Physics Institute, Armenia

Mo3-51 **Numerical Analysis of Radiation Build Up in FEL Oscillator**
S.I. Kuruma, M. Naruo, K. Mima, S. Nakai, C. Yamanaka
ILT/Osaka, Japan

Mo3-53 **A Self Consistent Analysis of Bunching and Harmonic Generation in Free Electron Laser**
G. Dattoli, L. Giannessi, P.L. Ottaviani , A. Torre
ENEA Frascati, Italy

Mo3-55 **Hybrid Resonators for FELs**
I. Kimel, L.R. Elias
CREOL-Univ. Central Florida, U.S.A.

Mo3-57 **A Confocal Ring Resonator for the CEBAF Infrared Free Electron Laser**
S.V. Benson, H.X. Liu, G.R. Neil, M. Xie
CEBAF, U.S.A.

Mo3-59 **Measurement and Correction of Magnetic Fields in Pulsed Slotted-Tube Microwigglers**
C.M. Fortgang, R.W. Warren
LANL Los Alamos, U.S.A.

Mo3-61 **3D Magnetic Field Wiggler Analysis for a FEL-Based Bunching Experiment**
J. Grenier, J. Gardelle, J.L. Rullier
CEA/CESTA, France

Mo3-63 **In-Vacuum Type Undulator for Visible/UV Region FEL Using Linac**
T. Keishi, A. Kobayashi, T. Tomimasu, T. Okazaki, Y. Hosoda
FELI, Osaka, Japan

Mo3-65 **Development of Electromagnetic Helical Microwiggler**
N. Ohigashi, K. Mima, Y. Tsunawaki, S. Ishii, N. Ikeda, K. Imasaki, M. Fujita, S.I. Kuruma, A. Murai, C. Yamanaka, S. Nakai
Kansai University, Japan

Session : Poster 2

15:30 Mo4-02 **High Intensity Racetrack Microtron as Free Electron Laser Driver**
V.G. Kurakin
Lebedev Institute, Russia

15:30	Mo4-04	**Initial Performance of the UCLA RF Photoinjector Gun** N. Barov, P.G. Davis, G. Hairapetian, S.C. Hartman, M. Hogan, C. Joshi, S. Park, C. Pellegrini, J. Rosenzweig, G. Travish, R.S. Zhang UCLA, U.S.A.
	Mo4-06	**Proposed Particle-Beam Characterizations for the APS Undulator Test Line** A.H. Lumpkin, M. Borland, S. Milton Argonne Nat. Lab, U.S.A.
	Mo4-08	**Electrons Generated by an UV Excimer Laser** V. Nassisi University of Lecce, Italy
	Mo4-10	**Superradiant Start Up of a Short Pulse FEL Oscillator** D.A. Jaroszynski, D. Oepts, A.F.G. van der Meer, R.J. Bakker, P.W. van Amersfoort FOM Rijnhuizen, The Netherlands
	Mo4-12	**Comparison Between a FEL Amplifier and Oscillator** P. Zambon, W.J. Witteman, P.J.M. van der Slot NCLR B.V., The Netherlands
	Mo4-14	**High-Power Cyclotron Autoresonance Maser (CARM) Experiments** J.L. Rullier, S. Alberti, B.G. Danly, E. Giguet, G. Gulotta, T. Kimura, W.L. Menninger, R.J. Temkin CEA/CESTA, France
	Mo4-16	**Study of Waveguide Mode Identification in FEL Experiment** K. Sakamoto, M. Shiho, S. Musyoki, A. Watanabe, Y. Kishimoto, S. Kawasaki, H. Ishizuka JAERI, Japan
	Mo4-18	**Design Elements for a FEL Operating in the VUV** F. Ciocci, G. Dattoli, A. De Angelis, F. Garosi, L. Giannessi, P.L. Ottaviani, A. Torre ENEA Frascati, Italy
	Mo4-20	**Generation of Harmonics Using the Multi-Cavity FEL** S. Krishnagopal, A.M. Sessler LBL Berkeley, U.S.A.

Session : Applications 2/Optical Technology for FELs *Chairman : T.I. Smith*

15:30 Mo4-22 **The Project of High Power Free Electron Laser Using Race-Track Microtron-Recuperator**

G.I. Erg, N.G. Gavrilov, E.I. Gorniker, G.N. Kulipanov, I.V. Kuptsov, G.Ya. Kurkin, A.D. Oreshkov, V.M. Petrov, I.V. Pinayev, V.M. Popik, I.K. Sedlyarov, T.V. Shaftan, A.N. Skrinsky, A.S. Sokolov, V.G. Veshcherevich, N.A. Vinokurov, P.D. Vobly

Budker Instit. of Nucl. Physics, Russia

Mo4-24 **Beam Conditioning in Storage Ring Driven FEL**

V.N. Litvinenko

Duke University, U.S.A.

Mo4-26 **Operation of a Small Infrared FEL System for Research and Student Training**

J.M.J. Madey, K.D. Straub

Duke University, U.S.A.

Mo4-28 **Progress of the IR FEL Development at JAERI**

M. Sugimoto, M. Takao, M. Sawamura, R. Nagai, R. Kato, N. Kikuzawa, E.J. Minehara, M. Ohkubo, Y. Kawarasaki, Y. Suzuki

FEL Lab. JAERI , Japan

Mo4-30 **Far-Infrared Capabilities at the Vanderbilt University Free-Electron Laser Center**

P.A. Tompkins, J.E. Walsh

Vanderbilt University, U.S.A.

Mo4-32 **Three-Dimensional Codes for Simulating e-Beam Transport and FEL Operation Including Space-Charge Effects**

Y. Pinhasi, M. Cohen, A. Gover

Tel-Aviv University, Israel

Mo4-34 **Computer Simulation of Micro-Cherenkov FEL Oscillator**

T. Taguchi, K. Mima

Setsunan University, Japan

Mo4-36 **Numerical Computations on the Entropylike Quantity of the Equilibrium Electrons in a Collective Free-Electron Laser**

S.C. Zhang, Q. Liu, Y. Xu

S-W Jiaotong University, People's Republic of China

Mo4-38 **Longitudinal Beam Compression in Free-Electron Lasers**

B. Hafizi, C.W. Roberson

Office of Naval Research, U.S.A.

Mo4-40 **The Effect of a Wiggler on Cyclotron Maser Instability**

G. Mishra

ENEA Frascati, Italy

15:30	Mo4-42	**Time-Dependent Behavior of a Short-Pulse FEL** J.K. Lee, S.J. Hahn, E.H. Park, T.H. Chung PIST Pohang, Korea
	Mo4-44	**The Simple Model of the Supermodes in FEL with a Intracavity Etalon** V.M. Popik, N.A. Vinokurov Budker Instit. of Nucl. Physics, Russia
	Mo4-46	**An Infrared Grating Free-Electron Laser** B. Hafizi, P.A. Sprangle, A. Fisher Icarus Research, U.S.A.
	Mo4-48	**FEL Gain Dependence on the Longitudinal Distribution of the Electron Beam Density in the Presence of Beat Waves** A.G. Shamamian Yerevan Physics Institute, Armenia
	Mo4-50	**About the Scheme of FEL with Synchronizing Magnetic Field for Beam Cooling and Operation with Hot Beams** S.A. Mikheev Kurchatov Institute, Russia
	Mo4-52	**Monochromatization of the FEL Radiation by the System of the Bound Resonators** V.I. Alexeev, E.G. Bessonov, M.L. Vnukova Lebedev Institute, Russia
	Mo4-54	**Dispersion Characteristics of Electromagnetically Pumped FEL** T.H. Chung, J.K. Lee Dong-A University, Korea
	Mo4-56	**Hole-Coupled Confocal Resonators for X-Ray Generation and Optical Storage** M. Xie, K.-J. Kim LBL Berkeley, U.S.A.
	Mo4-58	**Plasma Treatment of Dielectric-Coated Cavity Mirrors for Short Wavelength FEL** K. Yamada, T. Yamazaki, N. Sei, T. Mikado ETL Japan, Japan
	Mo4-60	**Undulator Magnetic Fields Measurements with Wire Deflection Method** A.A. Varfolomeev, A.S. Khlebnikov, N.S. Osmanov, S.V. Tolmachev Kurchatov Institute, Russia

15:30	Mo4-62	**Performance of the KIAE-4 Undulator for the FOM-FEM Project** A.A. Varfolomeev, S.N. Ivanchenkov, A.S. Khlebnikov, N.S. Osmanov, M.J. van der Wiel, W.H. Urbanus, V.F. Pavluchenkov Kurchatov Institute, Russia
	Mo4-64	**Three Dimensional Gain Analysis of FEL Using a Focusing Undulator with Alternately Shifted Permanent Magnets** Y. Tsunawaki, N. Ohigashi, K. Mima, S.I. Kuruma, K. Imasaki, M. Fujita, A. Murai, C. Yamanaka, S. Nakai Osaka Sangyo University, Japan

Tuesday

Session : Experimental Results 2 — *Chairman : C. Yamazaki*

8:30	Tu1-1	**First Operation of a Sheet-Beam, FEL Amplifier** V.L. Granatstein, W.W. Destler, Z.X. Zhang, J. Rodgers, B. Levush, T.M. Antonsen, D. Chen Univ. of Maryland, U.S.A.
8:50	Tu1-2	**Experimental Mode Analysis of a Circular Free Electron Laser** T. Mizuno, T. Ohtsuki, T. Ohshima, H. Saito ISAS Japan, Japan
9:10	Tu1-3	**Research on FELIX** A.F.G. van der Meer, FELIX Team FOM Rijnhuizen, The Netherlands
9:30	Tu1-4	**FEL Experiment on the UVSOR Storage Ring** H. Hama, J. Yamazaki, G. Isoyama UVSOR, Okazaki, Japan
9:50	Tu1-5	**Measurement of Enhanced Longitudinal Optical Modes from a Phase Locked Free-Electron Laser** E.B. Szarmes, A.D. Madden, J.M.J. Madey Duke University, U.S.A.
10:10	Tu1-6	**Powerful Cherenkov Microwave Amplifiers and Generators with Relativistic Explosion-Emitted Electron Beams** E. Abubakirov, N. Kovalev, N. Zaitsev IAP Nizhny Novgorod, Russia
10:30	*Coffee break*	

Session : Undulators — *Chairman : A.A. Varfolomeev*

11:00	Tu2-1	**Wiggler Imperfections in Free-Electron Lasers** H.P. Freund, R.H. Jackson SAIC, U.S.A.

11:20	Tu2-2	**Pulsed Wiggler-Pulsed Taper for High-Efficiency Resonator** H. Leboutet CEA/PTN, France
11:40	Tu2-3	**Fabrication of High-Field Short-Period Permanent Magnet Wigglers** R.W. Warren, C.M. Fortgang LANL Los Alamos, U.S.A.
12:00	Tu2-4	**Performance Characteristics of a Solenoid-Derived Wiggler** Y.C. Huang, H.C. Wang, J. Feinstein, R.H. Pantell Stanford University, U.S.A.
12:30	*Lunch*	

Session : Poster 1

14:00	Tu3-01	**Recirculation Scheme in the Second Phase of the JAERI FEL Project** M. Takao, M. Sugimoto, M. Sawamura, R. Nagai, R. Kato, E.J. Minehara, M. Ohkubo, Y. Suzuki FEL Lab. JAERI, Japan
	Tu3-03	**Design of a Beam Conditioning System for UT-FEL** R. Hajima, T. Muto, H. Ohashi University of Tokyo, Japan
	Tu3-05	**Development of a 10 MeV Microtron** K. Kuroda, K. Sugiyama, A. Takafuji, K. Koyanagi, I. Miura Centr. Res. Lab. Hitachi, Japan
	Tu3-07	**RF Power Tests for JAERI FEL Superconducting Accelerator Modules** M. Sawamura, M. Ohkubo, E.J. Minehara, R. Nagai, M. Takao, M. Sugimoto, R. Kato, N. Kikuzawa, Y. Suzuki FEL Lab. JAERI, Japan
	Tu3-09	**Photolithographic Imaging Experiments Using an Ultraviolet Free-Electron Laser** B.E. Newnam, J.W. Early, D.A. Byrd, V.K. Viswanathan, S.C. Bender, D.W. Feldman, C.M. Fortgang, J.C. Goldstein, P.G. O'Shea, R.L. Sheffield, R.W. Warren, T.J. Zaugg LANL Los Alamos, U.S.A.
	Tu3-11	**Application of a Millimetre-Wave Free-Electron Laser to Study Detection Processes** A. Doria, G.P. Gallerano, E. Giovenale, M.F. Kimmitt, G. Messina ENEA Frascati, Italy

14:00	Tu3-13	**A Powerful and Efficient Multibeam Microwave FEL** I. Boscolo, G. Jianming, P. Radaelli, V. Variale INFN Milan, Italy
	Tu3-15	**The UV Storage Ring Free Electron Laser for Time Resolved Fluorescence** M.E. Couprie, A. Delboulbé, D. Garzella, T. Hara, M. Billardon CEA DSM DRECAM SPAM, France
	Tu3-17	**Temporal Structure Behaviour and Longitudinal Instabilities on the Super ACO Free Electron Laser** D. Garzella, M.E. Couprie, A. Delboulbé, T. Hara, M. Billardon LURE Orsay, France
	Tu3-19	**Observations of Frequency, Phase and Saturation Characteristics of a Raman, Free-Electron Laser Amplifier** G. Bekefi MIT Cambridge, U.S.A.
	Tu3-21	**The Losses Measurement for Optical Cavity with Fabry-Perot Etalon** I.V. Pinayev, V.M. Popik, T.V. Shaftan, A.S. Sokolov, N.A. Vinokurov Budker Instit. of Nucl. Physics, Russia
	Tu3-23	***Microundulator Operation,* Resonantly Enhanced by a Strong Magnetic Guide Field** G. Spindler, G. Renz German Aerospace, Germany
	Tu3-25	**Generation of Femtosecond X-Rays by 90° Thomson Scattering** K.-J. Kim, S. Chattopadhay, C.V. Shank LBL Berkeley, U.S.A.
	Tu3-27	**Temporally and Spatially Variable Grating for Generation of Submillimeter and Far-Infrared Waves** C.M. Tang Naval Research Lab, U.S.A.
	Tu3-29	**Free Electron Lasers with Two-Dimensional Bragg Resonators** N.S. Ginzburg, N.Yu. Peskov, A.S. Sergeev IAP Nizhny Novgorod, Russia
	Tu3-31	**The Performance of the OK-4 Optical Klystron Installed on the Duke Storage Ring** V.N. Litvinenko, J.M.J. Madey, N.A. Vinokurov Duke University, U.S.A.

14:00	Tu3-33	**Radiation Complex on the Base of Racetrack Microtron** K.A. Belovintsev, A.I. Bukin, E.B. Gaskevich, A.I. Karev, A.V. Koltsov, V.A. Kuznetsov, V.G. Kurakin, S.V. Sidorov Lebedev Institute, Russia
	Tu3-35	**Status of the Liverpool Microwave FEL** R.A. Stuart, J. Lucas, G. Dearden, E.G. Quirk, A. Al-Shamma'a University of Liverpool, United Kingdom
	Tu3-37	**Status of the KAERI Millimeter-Wave Free-Electron Laser** B.C. Lee, S.K. Kim, S.O. Cho, Y.U. Jeong, B.H. Choi, J.M. Lee KAERI, Korea
	Tu3-39	**Exact and Variational Calculations of Eigenmodes for Three-Dimensional FEL Interaction in the Exponential Gain Regime** M. Xie LBL Berkeley, U.S.A.
	Tu3-41	**A Prebunched Microwave Free Electron Laser** R.A. Stuart, G. Kong University of Liverpool, United Kingdom
	Tu3-43	**Electron Beam Focusing by Nonhomogeneous Electromagnetic Wave in Inverse FEL** V.G. Baryshevsky, I.Ya. Dubovskaya, O.N. Metelitsa Institute of Nucl. Problems, Belorussia
	Tu3-45	**Tunability of a Tapered FEL Amplifier** B. Levush, H.P. Freund, T.M. Antonsen Univ. of Maryland, U.S.A.
	Tu3-47	**Spectral Width Limits in "Single Mode" FELs** S. Riyopoulus SAIC , U.S.A.
	Tu3-49	**Functional Scaling of the Optical Field of Free-Electron Lasers** S. Enguehard, B. Hatfield Appl. Math. Phys. Res. Inc., U.S.A.
	Tu3-51	**Pulse Stacking in FELIX** B. Faatz, E.H. Haselhoff, V.I. Zhulin, P.W. van Amersfoort FOM Rijnhuizen, The Netherlands
	Tu3-53	**Efficiency Enhancement of a FEL with Reversed Guide Field** A.A. Silivra, I.A. Goncharov Kiev University, Ukraine

14:00	Tu3-55	**Modified Theory of Smith-Purcell Radiation** N.K. Zhevago, V.I. Glebov Kurchatov Institute, Russia
	Tu3-57	**Dynamics of Electron Beam in Ion Undulator** Yu.Ya. Golub, N.E. Rozanov Moscow Rad. Institute, Russia
	Tu3-59	**Undulator Scheme Providing Wide Range Magnetic Field Tuning** A.A. Varfolomeev, A.S. Khlebnikov, N.S. Osmanov Kurchatov Institute, Russia
	Tu3-61	**Tapered Twin Helical Undulator for Lasing on Selected Harmonic** E.B. Gaskevich Lebedev Institute, Russia
	Tu3-63	**Progress with the Hybrid Microwiggler** Q.X. Liu, G.Y. Wang, S.Z. Yang, C.M. Zhou, Z.X. Hui SIEE Chengdu, People's Republic of China
	Tu3-65	**Microwave Free-Electron Laser Amplifier Experiments on SG-1 Device** Zhongxi Hui, Chuanming Zhou, Ruian Wu, Jianjun Deng, Yutao Chen, Bonan Ding, Longzhou Tang, Jun Zhang, Fanbao Meng, Zuchong Tao, Zhenhua Yang, Shihong Tain, Zhiwei Dong, Shangqing Wu, Xiaojian Shu Instit. Appl. Physics, Beijing, People's Republic of China

Session : Poster 2

15:30	Tu4-02	**Measurement of Actual Emittance of Relativistic Electron Beams** L. Fu, N. Liu, J. Dai, X. Chen Tsinghua Univ. , People's Republic of China
	Tu4-04	**Design and Construction of Induction LINAC for MM Wave Free Electron Laser for Fusion Research** M. Shiho, S. Kawasaki, K. Sakamoto, H. Maeda, H. Ishizuka, Y. Watanabe, A. Tokuchi, Y. Yamashita, S. Nakajima JAERI, Japan
	Tu4-06	**Photoinjector for 6 MeV S-band RF Linac at ILT/ILE Osaka University** M. Fujita, K. Imasaki, J. Chen, S.I. Kuruma, H. Furukawa, C. Yamanaka, M. Asakawa, N. Sakamoto, T. Yamamoto, N. Inoue, S. Nakai, Y. Tsunawaki. T. Agari, T. Asakuma, N. Ohigashi ILT/Osaka, Japan

15:30	Tu4-08	**Development of an Electrostatic Accelerator for a Millimeter-Wave Free-Electron Laser** S.O. Cho, B.C. Lee, S.K. Kim, Y.U. Jeong, B.H. Choi, J.M. Lee Seoul Nat. University, Korea
	Tu4-10	**Excite-Probe FEL (CLIO) Study of Two-Photon-Induced Carrier Dynamics in Narrow Gap Semiconductors** B.N. Murdin, R. Rangel-Rojo, C.R. Pidgeon, M.F. Kimmitt, A.K. Kar, D.A. Jaroszynski Heriot-Watt University, United Kingdom
	Tu4-12	**Inverse Free Electron Laser Accelerator Development** A. Fisher, J.C. Gallardo, A. van Steenbergen, J. Sandweiss BNL, U.S.A.
	Tu4-14	**CLIC Drive Beam Generation by Induction Linac and FEL Preliminary Experimental Studies** J. Gardelle, R. Corsini, J. Grenier, C. Johnson, J.L. Rullier CEA/CESTA, France
	Tu4-16	**Generation of the Second Harmonic in a FEL with an Axisymmetric Undulator of the Induction Type** V.D. Sazhin, N.I. Karbushev, P.V. Mironov Moscow Rad. Institute, Russia
	Tu4-18	**Generation of Intense Coherent Undulator Radiation Using a High-Current Relativistic Photoelectron Beam Generated by an Ultra-Short Excimer Laser Pulse** Y.U. Jeong, Y. Kawamura, K. Toyoda, C.H. Nam, S.S. Lee KAERI, Korea
	Tu4-20	**Bunch Length Measurement on CLIO** F. Glotin, J.M. Berset, R. Chaput, D.A. Jaroszynski, J.M. Ortéga, R. Prazérès LURE Orsay, France
	Tu4-22	**Observations of the Super-ACO FEL Micropulse with a Streak Camera** T. Hara, M.E. Couprie, A. Delboulbé, P. Troussel, D. Gontier, M. Billardon LURE Orsay, France
	Tu4-24	**Coherent Spontaneous Radiation and Superradiant Amplification of Ultra-Short Microwave Pulses from a Photocathode Linac FEL** G.P. LeSage, F.V. Hartemann, D.B. McDermott, N.C. Luhmann, P.G. Davis, S.C. Hartman, S. Park, R.S. Zhang, C. Pellegrini UCLA, U.S.A.

15:30	Tu4-26	**High Gain FELs for the Duke Storage Ring** B. Burnham, V.N. Litvinenko, J.M.J. Madey, Y. Wu Duke University, U.S.A.
	Tu4-28	**On Application of Time-Dependent Undulator Tapering to Increase a FEL Oscillator Efficiency** E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov ASC-USSR, Russia
	Tu4-30	**The Ultrashort Impulses Formation in a FEL with Electromagnetic Pump Wave** A.A. Silivra, N. Ya. Kotsarenko, A.B. Draganov Kiev University, Ukraine
	Tu4-32	**Status Report on the CEBAF IR FEL** G.R. Neil, S.V. Benson, J.J. Bisognano, Y. Chao, D. Douglas, H.F. Dylla, L. Harwood, C.W. Leemann, H.X. Liu, P. Liger, D. Machie, D.V. Neuffer, C. Rode, S.N. Simrock, C.K. Sinclair, J. VanZeijts, B. Yunn CEBAF, U.S.A.
	Tu4-34	**Linac Driver for the FEL Project at P.N. Lebedev Institute** A.V. Agafonov, G.A. Gevorgyan, E.G. Krastelev, A.Yu. Kustov, A.N. Lebedev, N.N. Martynchuk, P.S. Mikhalev, V.A. Fedotov, S.M. Zakharov, B.N. Yablokov Lebedev Institute, Russia
	Tu4-36	**Electron-Beam Diagnostics for the Average Power Laser Experiment/High Power Oscillator (Aple/HPO) Program** M.D. Wilke, D. Gilpatrick, D. Barlow, R. Greegor, D.H. Dowell Boeing Seattle, U.S.A.
	Tu4-38	**FEM Experiment with Prebunched Beam at TAU: Status Report** M. Arbel, D. Ben-Haim, M. Cohen, M. Draznin, A. Eichenbaum, A. Gover, H. Kleinman, A. Kugel, Y. Pinhasi, Y. Yakover Tel-Aviv University, Israel
	Tu4-40	**A Free-Electron Laser Model without the Slowly Varying Envelope Approximation** E.H. Haselhoff FOM Rijnhuizen, The Netherlands
	Tu4-42	**Controlling the Rate of Harmonics in a Free Electron Laser** D. Iracane, D. Touati, P. Chaix CEA/PTN, France

15:30	Tu4-44	**Free Electron Gain Scaling Function Including Alternating Gradient Focusing** L.H. Yu, C.M. Hung, D. Li, S. Krinsky BNL, U.S.A.
	Tu4-46	**Simulations of Performance of the FEM Oscillator for Fusion at 130-250 GHz** A.V. Tulupov, M.J. van der Wiel, W.H. Urbanus, M. Caplan FOM Rijnhuizen, The Netherlands
	Tu4-48	**Electron Beam Conditioning Methods in Free-Electrons Lasers** P.A. Sprangle, B. Hafizi, G. Joyce, P. Serafim Naval Research Lab, U.S.A.
	Tu4-50	**Electron Velocity Instability in Combined Helical Wiggler and Axial Guide Magnetic Fields** Xiaojian Shu Instit. Appl. Physics, Beijing, People's Republic of China
	Tu4-52	**Evalution of Gain in ETL FEL Oscillation with Optical Klystron** K. Yoshikawa, S. Hashimoto, M. Ohnishi, Y. Yamamoto, T. Yamazaki, K. Yamada, N. Sei IAE, Kyoto University, Japan
	Tu4-54	**Simulation of Reversed and Conventional Guide Field Operation in a Free Electron Laser** G. Renz, G. Spindler German Aerospace, Germany
	Tu4-56	**Electronic Orbits in a Helical Wiggler with Axial Guide Field** J.T. Donohue, J.L. Rullier CEA/CESTA, France
	Tu4-58	**Influence of the Radiation Force on Free-Electron Laser Gain** A.V. Serov Lebedev Institute, Russia
	Tu4-60	**Selected Applications of Planar Permanent Magnet Multipoles in FEL Insertion Device Design** R. Tatchyn SSRL Stanford, U.S.A.
	Tu4-62	**Hybrid Microundulator Design for the CREOL Compact CW-FEL** M. Tecimer, L.R. Elias CREOL-Univ. Central Florida, U.S.A.

15:30	Tu4-64	**Magnetic Measurements of a Hybrid Permanent Magnet Undulator for the LISA-SURF IR FEL Experiment** L. Barbagelata, S. Curotto, M. Grattarola, G. Gualco, F. Rosatelli, F. Ciocci, A. Renieri Ansaldo Ricerche, Italy

Wednesday

Session : Applications 1 *Chairman : C. Brau*

8:30	We1-1	**Probing Terahertz Electron Dynamics in Semiconductor Nanostructures with the UC Santa Barbara FEL** J.P. Kaminski, S.J. Allen, M.S. Sherwin, B. Keay, J.S. Scott, K. Craig, J. Heyman, P. Guimaraes UCSB, California, U.S.A.
8:50	We1-2	**The FEL as a Tool for Assessment of Parameters in the Medical Use of Lasers** B. Jean, T. Bende, T. Seiler, C. Brau University of Tübingen, Germany
9:10	We1-3	**Free Electron Laser-Induced Bleaching of the Intersubband Absorption in Semiconductor Quantum Wells** B.N. Murdin, M. Helm, C.R. Pidgeon, K.K. Geerinck, J.N. Hovenier, W.Th. Wenckebach, A.F.G. van der Meer, P.W. van Amersfoort Heriot-Watt University, United Kingdom
9:30	We1-4	**Adsorbate Vibrational Spectroscopy by IR-Visible Sum-Frequency Generation Using CLIO-FEL: CO from CH3OH on Pt and H/Si(111)-(1X1)** A. Peremans, A. Tadjeddine, M. Suhren, P. Dumas, J.M. Berset, F. Glotin, J.M. Ortéga LURE-CNRS Orsay, France
9:50	We1-5	**Free-Electron Lasers and Semiconductor Physics: First Results on Interfaces and Non-Linear Optics** G. Margaritondo, C. Coluzza, E. Tuncel, J.L. Staehli, F. Gozzo, P.A. Baudat, D. Martin, F. Morier-Genoud, C. Dupuy, A. Rudra, M. Ilegems, J.T. McKinley, A. Ueda, A.V. Barnes, R.G. Albridge, X. Yang, N.H. Tolk Ecole Polytechnique Fédérale, Lausanne, Switzerland
10:10	We1-6	**Nonlinear Optics with a Free-Electron Laser** E.R. Eliel, Q.H.F. Vrehen, M. Barmentlo, G.W. 't Hooft, A.F.G. van der Meer, P.W. van Amersfoort Leiden University, The Netherlands
10:30	*Coffee break*	

		Session : Applications 2/Optical Technology for FELs	*Chairman : T.I. Smith*
11:00	We2-1	**Free-Electron Laser Power Beaming to Satellites at China Lake, California** H.E. Bennett, J.D.G. Rather, E.E. Montgomery IV Naval Air Warfare Center, U.S.A.	
11:20	We2-2	**Photoluminescence as a Probe of the Interaction of Intense Far-Infrared Radiation with Semiconductor Quantum Structures** P.C. van Son, J. Cerne, M.S. Sherwin, S.J. Allen, M. Sundaram, I.-H. Tan, D. Bimberg Delft University, The Netherlands	
11:40	We2-3	**Measurement of Single-Pulse Spectra of an Infrared FEL** W.P. Leemans, J.A. Edighoffer, K.-J. Kim, S. Chattopadhay, H.A. Schwettman LBL Berkeley, U.S.A.	
12:00	*Departure for technical visits*		

Thursday

		Session : Theory 1	*Chairman : R. Bonifacio*
8:30	Th1-1	**Frequency Shifting Phenomena in Free-Electron Lasers (invited)** G. Shvets, J.S. Wurtele MIT Cambridge, U.S.A.	
9:10	Th1-2	**Surface Quasi-Cherenkov FEL** V.G. Baryshevsky, K.G. Batrakov, I.Ya. Dubovskaya Institute of Nucl. Problems, Belorussia	
9:30	Th1-3	**Suppression of the Sideband Instability in Tapered FELs and IFELs** A. Bhattacharjee, R.V. Pilla Colombia University, U.S.A.	
9:50	Th1-4	**Superradiance of Ensembles of Classical Electron-Oscillators as a Method for the Generation of Ultrashort Electromagnetic Pulses** N.S. Ginzburg, Y.V. Novozhilova, A.S. Sergeev IAP Nizhny Novgorod, Russia	
10:10	Th1-5	**Electron Trajectories in a Free Electron Laser with a Reversed Axial Guide Field** A. Bourdier, V.A. Bazylev, Ph. Gouard, J.M. Buzzi CEA/PTN, France	
10:30	*Coffee break*		

	Session : Accelerators For FELs	Chairman : H.L. Hagedoorn
11:00	Th2-1	**An Eight Centimeter Long Accelerator for a Far Infrared FEL** J.F. Schmerge, J.W. Lewellen, Y.C. Huang, J. Harris, J. Feinstein, L. Zitelli, R.H. Pantell Stanford University, U.S.A.
11:20	Th2-2	**A Novel Laser Driven RF Structure for the Generation of Bright Electron Beams** L. Serafini INFN Milan, Italy
11:40	Th2-3	**Performance of the High Brightness Linac for the Advanced Free-Electron Laser Initiative at Los Alamos** R.L. Sheffield, R.H. Austin, B.E. Carlsten, K.D.C. Chan, W.J.D. Johnson, S.M. Gierman, J.M. Kinross-Wright, S.H. Kong, K.L. Meier, J.G. Plato, D.C. Nguyen, S.J. Russel, B.A. Sherwood, C.A. Timmer, M.E. Weber, L.M. Young LANL Los Alamos, U.S.A.
12:00	Th2-4	**Developments on the TEUFEL Injector Racetrack Microtron** J.I.M. Botman, J.L. Delhez, H.L. Hagedoorn, W.J.G.M. Kleeven, C.J. Timmermans, G.A. Webers, G.J. Ernst, J.W.J. Verschuur, W.J. Witteman Eindhoven University, The Netherlands
12:30	*Lunch*	

	Session : Poster 1	
14:00	Th3-01	**Magnetic Bunching Experiments on ELSA** S. Joly, D.H. Dowell, ELSA-FEL Team CEA/SPTN, France
	Th3-03	**Single Bunch Injection of the Storage Ring NIJI-IV for FEL** M. Yokoyama, M. Kawai, S. Hamada, K. Owaki, T. Yamazaki, T. Mikado, K. Yamada, N. Sei, S. Sugiyama, H. Ohgaki, T. Noguchi, R. Suzuki, M. Chiwaki, T. Tomimasu Kawasaki Heavy Indus. Ltd, Japan
	Th3-05	**Progress Report of the FEL Injector at CIAE** W.Z. Zhou, T.L. Yang, X.L. Zhai, X.Z. Shi, Z.M. Jin, D.X. Pu, Q. Sun, Y.Z. Lu, W.K. Chen CIAE Beijing, People's Republic of China
	Th3-07	**A 5-MeV Electron Injector and the FELI Linac** T. Tomimasu, Y. Morii, A. Koga, Y. Miyauchi, S. Sato, T. Keishi, S. Abe, A. Kobayashi, I. Bessho, A. Nagai FELI, Osaka, Japan

14:00	Th3-09	**New Semiconductor Spectroscopy and Alblation Studies with the Vanderbilt Free-Electron Laser** N.H. Tolk, R.G. Albridge, A.V. Barnes, G. Margaritondo, J.T. McKinley, A. Ueda Vanderbilt University, U.S.A.
	Th3-11	**Industrial Applications of Free Electron Lasers** J. Lucas, R.A. Stuart University of Liverpool, United Kingdom
	Th3-13	**Compact Waveguide FEL for Spectroscopic Measurements in Muonic Hydrogen** F. Ciocci, F. Della Valle, A. Doria, G.P. Gallerano, L. Giannessi, E. Giovenale, P. Hauser, F. Kottmann, G. Messina, E. Milotti, C. Petitjean, L. Picardi, A. Renieri, C. Rizzo, C. Ronsivalle, L.M. Simons, D. Taqqu, A. Vacchi, A. Vignati, E. Zavattini ENEA Frascati, Italy
	Th3-15	**Recent Results of the ELSA-FEL** S. Joly, Ph. Guimbal, FEL Team CEA/SPTN, France
	Th3-17	**Experimental Investigations of an External Feedback System for Wavelength Selection of High-Power Microwave Radiation in a *Free-Electron Maser Regime*** V.A. Bogachenkov, V.A. Papadichev, I.V. Sinilschikova, O.A. Smith Lebedev Institute, Russia
	Th3-19	**Optical Mode Analysis on the CLIO Infrared FEL** R. Prazérès, J.M. Berset, F. Glotin, D.A. Jaroszynski, J.M. Ortéga LURE Orsay, France
	Th3-21	**A Millimeter Wavelength FEL Driven by a Photocathode RF Linac** G.P. LeSage, F.V. Hartemann, C. Joshi, D.B. McDermott, N.C. Luhmann, C. Pellegrini, J. Rosenzweig, R.S. Zhang, R. Bonifacio, L. DeSalvo Souza, P. Pierini INFN Milan, Italy
	Th3-23	**A 1 MW, 130-250 GHz, Free-Electron Maser for Fusion** W.H. Urbanus, C.A.J. van der Geer, A. van der Linden, A.B. Sterk, A.V. Tulupov, A.G.A. Verhoeven, M.J. van der Wiel, A.A. Varfolomeev, A.S. Khlebnikov, V.L. Bratman, G.G. Denisov FOM Rijnhuizen, The Netherlands
	Th3-25	**Design and Construction of a Compact IR FEL** I.S. Lehrman, J.R. Sheehan, J. Krishnaswamy, R.H. Heuer, M.F. Reush, R. Hartley Grumman Aerospace Co., U.S.A.

14:00	Th3-27	**The Parametric Free-Electron Laser in Submillimeter Wave-Length Region** V.I. Alexeev, K.A. Belovintsev, E.G. Bessonov, A.V. Koltsov, A.V. Serov Lebedev Institute, Russia
	Th3-29	**CARMS at the Millimeter and Submillimeter Wavelengths** V.L. Bratman IAP Nizhny Novgorod, Russia
	Th3-31	**Application of a 3D Time Dependent Code for Predicting the Spectral Purity and Stability of the 1MW 200 GHz FOM FEM Oscillator** M. Caplan LLNL Livermore, U.S.A.
	Th3-33	**Analytical Derivation of OK and FEL 3-D Gain for Finite Emittance and Energy Spread Electron Beam** V.N. Litvinenko Duke University, U.S.A.
	Th3-35	**3-D Simulations of FEL Oscillator** Z. Weng, Y. Shi IAEC Beijing, People's Republic of China
	Th3-37	**Three-Dimensional Simulation of Littrow-Grating Sideband Suppression in a 10 KW Free-Electron Laser** D.C. Quimby, C.G. Parazzoli STI Optronics, U.S.A.
	Th3-39	**Analysis and Optical Design Study of Tapered FEL Amplifiers on the Borders of Raman and Compton Regimes** S. Kawasaki, M. Takahasi, H. Ishizuka, K. Sakamoto, Y. Kishimoto, S. Musyoki, A. Watanabe, M. Shiho Saitama University, Japan
	Th3-41	**On the Plasma Based FELs** V.A. Bazylev, T.J. Schep, A.V. Tulupov Kurchatov Institute, Russia
	Th3-43	**Space-Charge Models in Raman FEL Simulations** G. Zhang, J.S. Wurtele MIT Cambridge, U.S.A.
	Th3-45	**Cherenkov Generation of Rayleigh Electromagnetic Wave in Gyrotropic Plasma Waveguide** S.T. Ivanov, E.G. Alexov Sofia University, Bulgaria

14:00	Th3-47	**Chaos in Free-Electron Lasers** C. Chen MIT Cambridge, U.S.A.
	Th3-49	**1-D Simulation of a Waveguide Free-Electron Laser Using Bragg Reflectors** S.K. Kim, B.C. Lee, S.O. Cho, Y.U. Jeong, B.H. Choi, J.M. Lee KAERI, Korea
	Th3-51	**Experiments with Undulator Radiation of a Single Electron** I.V. Pinayev, V.M. Popik, T.V. Shaftan, A.S. Sokolov, N.A. Vinokurov, P.V. Vorobyov Budker Instit. of Nucl. Physics, Russia
	Th3-53	**Microwave Transport in the Ion-Channel Guided Free-Electron Laser** K. Takayama, J. Kishiro, T. Ozaki, K. Ebihara, T. Kikunaga, H. Katoh KEK Japan, Japan
	Th3-55	**Hard X-Ray Production in a Visible-Wavelength Free-Electron Laser** J.C. Gallardo BNL, U.S.A.
	Th3-57	**Stable-Unstable Free-Electron Laser Resonators** C.C. Shih TRW, U.S.A.
	Th3-59	**Advanced Hybrid Undulator Schemes Providing Enhanced Transverse E-Beam Focusing** A.A. Varfolomeev, A.H. Hairetdinov Kurchatov Institute, Russia
	Th3-61	**Helical Undulator for Far Infrared Free Electron Laser** A.I. Bukin, E.B. Gaskevich, V.G. Kurakin, O.V. Savushkin Lebedev Institute, Russia
	Th3-63	**Investigation of Raman Free-Electron Lasers with a Novel Bifilar Helical Small-Period Wiggler** B. Feng, M.C. Wang, Z. Wang, Z. Lu, L. Zhang SIO & FM Shanghai, People's Republic of China
	Th3-65	**Operation of the CLIO Infrared Laser Facility** J.M. Ortéga LURE Orsay, France

15:30	Th4-02	**High Frequency Photocathode RF Gun Performance** S.C. Chen, J. Gonichon, C.L. Lin, S. Trotz, B.G. Danly, R.J. Temkin, J.S. Wurtele MIT Cambridge, U.S.A.
	Th4-04	**Power and Efficiency Optimization of the Compact CREOL FEL** L.R. Elias, I. Kimel, K. Hopkins, M. Tecimer, P. Tesch CREOL-Univ. Central Florida, U.S.A.
	Th4-06	**Design of a By-Pass Line for an Undulator for the Storage Ring EUTERPE** M. Venier, B. Xi, J.I.M. Botman, M. Conte Eindhoven University, The Netherlands
	Th4-08	**Transport of RF-photocathode Gun Produced Beam with Contained Emittance Growth** J.C. Gallardo, H. Kirk, X. Zhang BNL, U.S.A.
	Th4-10	**Infrared FEL Photochemistry: Multiple-Photon Dissociation of Freon Gas** B.E. Newnam, J.W. Early, J.L. Lyman LANL Los Alamos, U.S.A.
	Th4-12	**A FEL Study of the Saturation Intensity of a Donor Transition in Si:P** K.K. Geerinck, J.E. Dijkstra, J.N. Hovenier, T.O. Klaassen, W.Th. Wenckebach, A.F.G. van der Meer, P.W. van Amersfoort Delft University, The Netherlands
	Th4-14	**FEL Based Photon Collider at SLC as a Prototype of Future Photon Colliders** E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, M.V. Yurkov JINR-Russia, Russia
	Th4-16	**Narrow-Band Operation of FELIX** D. Oepts, R.J. Bakker, D.A. Jaroszynski, A.F.G. van der Meer, P.W. van Amersfoort FOM Rijnhuizen, The Netherlands
	Th4-18	**Traveling-Wave Cyclotron (TWC) Free-Electron Maser** E. Jerby, G. Bekefi Tel-Aviv University, Israel
	Th4-20	**3 MM Wave Free Electron Laser (FEL) with a New Small Period Wiggler** M.C. Wang, Z. Lu, L. Zhang, B. Feng, Z. Wang SIO & FM Shanghai, People's Republic of China

15:30	Th4-22	**Microwave Amplifiers and Generators of the Cherenkov Type with Relativistic Electron Beams Produced by Field-Emission Guns** E. Abubakirov, N. Kovalev, N. Zaitsev IAP Nizhny Novgorod, Russia
	Th4-24	**The Israeli Tandem Electrostatic Accelerator FEL-Status Report** M. Draznin, A. Goldring, A. Gover, Y. Pinhasi, J. Wachtell, Y. Yakover, J. Sokolowski, B. Mandelbaum, A. Rosenberg, Y. Shiloh, G. Hazak, L.M. Levine, O. Shahal Tel-Aviv University, Israel
	Th4-26	**The Project of New Laser Technological Center** F.F. Baryshnikov, N.V. Cheburkin, V.V. Perebeynos, A.N. Skrinsky, N.A. Vinokurov Budker Instit. of Nucl. Physics, Russia
	Th4-28	**Present Status of the NIJI-IV Free-Electron Laser** T. Yamazaki, K. Yamada, S. Sugiyama, H. Ohgaki, N. Sei, T. Mikado, T. Noguchi, M. Chiwaki, R. Suzuki, M. Kawai, M. Yokoyama, S. Hamada ETL Japan, Japan
	Th4-30	**FEL-Generator and FEL-Amplifier Facility in JINR** A.A. Kaminsky, A.K. Kaminsky, V.P. Sarantsev, S.N. Sedykh, A.P. Sergeev JINR, Russia
	Th4-32	**3D Simulations of High Power FEM Oscillator** A.A. Varfolomeev, M.M. Pitatelev Kurchatov Institute, Russia
	Th4-34	**A Theory of the Beam-Wave Interaction for a Dielectric Cherenkov Maser Operation in Non-Axisymmetric Mode** A.S. Shlapakovskii, K.A. Chirko Tomsk Polytech. University, Russia
	Th4-36	**Coherence of Undulator Radiation and Ultra-Relativistic Free-Electron Laser Efficiency** V.I. Kurilko, V.V. Ognivenko Kharkov Institute, Ukraine
	Th4-38	**Computations of Longitudinal Electron Dynamics in the Recirculating CW RF Accelerator-Recuperator of the High Average Power FEL** A.S. Sokolov, N.A. Vinokurov Budker Instit. of Nucl. Physics, Russia

15:30	Th4-40	**The Nonlinear Analysis of Self-field Effects in Free-Electron Lasers** H.P. Freund, R.H. Jackson, D.E. Pershing SAIC, U.S.A.
	Th4-42	**Beam Transport Through Two Section Undulator. Computer Simulation Results** A.A. Varfolomeev, A.V. Smirnov Kurchatov Institute, Russia
	Th4-44	**Numerical Investigation of the Longitudinal Phasespace of Storage Ring FELs** A. Geisler University of Dortmund, Germany
	Th4-46	**Radiative Interaction of Charges in Plasma** S.T. Zavtrak Institute of Nucl. Problems, Belorussia
	Th4-48	**Coherent and Incoherent Evolution in the Raman Free-Electron Laser** C. Penman University of Twente, The Netherlands
	Th4-50	**Nonlinear Coupling of the Space-charge and Transverse Magnetic Waves in a High Power Cherenkov Maser** J.S. Choi, B.H. Hong, D.I. Choi Dongshin University, Korea
	Th4-52	**Design of a 30 GHz Bragg Reflector for a Raman FEL** P. Zambon, P.J.M. van der Slot NCLR B.V., The Netherlands
	Th4-54	**Peculiarities of the Harmonic Generation in the System of the Identical Undulators** E.G. Bessonov Lebedev Institute, Russia
	Th4-56	**Simulations of Non-Immersed Cathode FEL Experiments with Helical Wiggler and Solenoid** J. Gardelle, Ph. Gouard, J. Labrouche, P. Le Taillandier CEA/CESTA, France
	Th4-58	**Microwave Systems for Millimeter and Submillimeter Free Electron Masers** G.G. Denisov IAP Nizhny Novgorod, Russia

15:30	Th4-60	**The Coaxial Hybrid Iron (CHI) Wiggler** R.H. Jackson, H.P. Freund, D.E. Pershing Naval Research Lab, U.S.A.
	Th4-62	**Plane Electromagnetic Undulators of the P.N. Lebedev Physical Institute** V.A. Papadichev, V.S. Vysotsky, V.N. Tsikhon, S.G. Deryagin, V.T. Eremichev, V.A. Bogachenkov, O.A. Smith, S.M. Zakharov Lebedev Institute, Russia
	Th4-64	**An Undulator for FELICITA I** T. Schmidt, F. Brinker, D. Nölle Universität Dortmund, Germany
	Th4-66	**Optical Alignment and Beam Extraction at the CLIO Infrared Laser Facility** J.M. Berset, F. Glotin, R. Prazérès, J.M. Ortéga LURE Orsay, France

Friday

Session : FEL New Concepts *Chairman : A. Sessler*

8:30	Fr1-1	**The SLAC Soft X-Ray High Power FEL (invited)** C. Pellegrini, J. Rosenzweig, G. Travish, K. Bane, R. Boyce, G. Loew, P. Morton, H.-D. Nuhn, J. Paterson, P. Pianetta, T. Raubenheimer, J. Seeman, R. Tatchyn, V. Vylet, H. Winick, K. Halbach, K.-J. Kim, M. Xie, D. Prosnitz, T. Scharlemann UCLA, U.S.A.
9:10	Fr1-2	**Micro Cherenkov FEL Driven by FEA** K. Mima, T. Taguchi, N. Ohigashi, Y. Tasunawaki, M. Shiho, S.I. Kuruma, R. Imashioya, S. Nakai ILE, Osaka University, Japan
9:30	Fr1-3	**Free-Proton Lasers Based on the High Energy Accelerators as the High Power, High Efficiency CM-to X-Ray Machine** E.G. Bessonov Lebedev Institute, Russia
9:50	Fr1-4	**Development of a Compact Laser Undulator Soft X-Ray Source** J. Chen, M. Fujita, K. Imasaki, C. Yamanaka, M. Asakawa, S. Nakai ILT/Osaka, Japan
10:10	Fr1-5	**An Accelerator/Wiggler for High Efficiency FEL Operation** J.W. Lewellen, J.F. Schmerge, J. Harris, J. Feinstein, R.H. Pantell Stanford University, U.S.A.
10:30	*Coffee break*	

	Session : Theory 2	Chairman : H.P. Freund
11:00	Fr2-1	**A Study of Linewidth, Noise and Fluctuations in a FEL Operating in Sase** P. Pierini, N. Piovella, L. DeSalvo Souza, R. Bonifacio, C. Pellegrini INFN Milan, Italy
11:20	Fr2-2	**A Solitary Wave Theory for Spiking Pulses Emitted by a Raman Free Electron Laser** L.Y. Lin, T.C. Marshall Colombia University, U.S.A.
11:40	Fr2-3	**Up Frequency Conversion in a Two Resonant Waves High Gain FEL Amplifier** N. Piovella, V. Petrillo, C. Maroli, R. Bonifacio Univ. di Milano, Italy
12:00	Fr2-4	**Tunable, Short Pulse Hard X-Rays from a Compact Laser Synchrotron Source** P.A. Sprangle, A. Ting, E. Esarey, A. Fisher Naval Research Lab, U.S.A.
12:30	*End of conference*	

INITIAL PERFORMANCE OF LOS ALAMOS ADVANCED FREE ELECTRON LASER*

D.C. Nguyen, R.H. Austin, K.C.D. Chan, C. Fortgang, W.J.D. Johnson, S.M. Gierman, J. Kinross-Wright, S.H. Kong, K.L. Meier, J.G. Plato, S.J. Russell, R.L. Sheffield, B.A. Sherwood, C.A. Timmer, R.W. Warren, and M.E. Weber.
Mail Stop H825, Los Alamos National Laboratory
Los Alamos, NM 87545

We report results on the high-brightness electron linac and initial performance of the Advanced FEL at Los Alamos. The design and construction of the Advanced FEL beamline are based upon integration of advanced technologies such as a high-brightness photoinjector, a high-gradient compact linac, and permanent-magnet beamline components. With a 1.4-m long optical resonator, the Advanced FEL will be the first of its kind small enough to be mounted on an optical table, yet capable of providing high-power optical output spanning the near-ir. The photoinjector, consisting of high quantum-yield K_2CsSb photocathodes gated by a modelocked Nd:YLF oscillator and amplifiers, produces up to 3 nC in 10-ps bunches at a pulse repetition rate of 108.33 MHz. The high-gradient accelerator consists of 11 rf half-cells and is powered by a 1300-MHz Klystron capable of producing 10 kW of average power. At a peak current greater than 250 A, the instantaneous electron beam emittance is 6π mm mrad. The highest electron beam energy achieved is 18 MeV with an energy spread of approximately 1%. 100% of the high-brightness electron beam is successfully transmitted through a 2.7-mm id wiggler tube. The wiggler is a samarium cobalt microwiggler with 24 periods, each 1 cm long, and a peak magnetic field of 0.4 Tesla. The FEL resonator consists of two concave multilayer dielectric (ZnSe/ThF4) mirrors with a radius of curvature of 0.7 m. Initial lasing occurred in the 4.5 - 5.5 μm region with a peak output pulse energy of 7 mJ in 2-μs pulses.

* Work supported by Los Alamos National Laboratory Exploratory Research and Development Initiative, under the auspices of the United States Department of Energy.

FIRST OBSERVATION OF AMPLIFICATION OF SPONTANEOUS EMISSION ACHIEVED WITH THE DARMSTADT IR FEL *

J. Auerhammer, H. Genz, H.-D. Gräf, W Grill[1], R. Hahn, A. Richter
V. Schlott, F. Thomas, J. Töpper, H. Weise, T. Wesp and M. Wiencken

Institut für Kernphysik
Technische Hochschule Darmstadt, Schlossgartenstr. 9
64289 Darmstadt, Germany

[1]*Physikalisches Institut*
Universität Frankfurt, Robert-Mayer-Str. 2-4
60054 Frankfurt, Germany

Utilising electron beams of 32.8 and 38.0 MeV delivered by the new superconducting electron accelerator S–DALINAC, extensive investigations regarding the electron beam specifications, the observation of spontaneous emission and the quality of the optical cavity have been performed. Employing electron beams with peak currents up to 2 A and pulses of 2 ps length the quantities pulse structure, charge per pulse, energy and energy resolution were studied and found to meet or almost reach the requirements needed for lasing. Despite the very low intensity of this FEL experiment, spectra of spontaneous emission could be recorded for the first and third harmonic at 4.80 and 1.63 μm for 38 MeV and 6.7 and 2.23 μm for 32.8 MeV , respectively. Light emitted by the seventh, ninth and eleventh harmonic was clearly visible using a telescope placed 60 m apart from its origin. The spectral width of the third harmonic has been analyzed and explained by the experimental conditions. An accumulation of intensity up to twelve times the intensity originating from a single photon pulse could clearly be identified, which can be interpreted as a lower limit of at least twelve round trips of photon pulses within the cavity. Length adjustment was achieved by changing the preadjusted mirrors by means of piezo elements and dc motors. A length region with distinct amplification of the spontaneous emission intensity could be established unequivocally.

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* Supported by Bundesministerium für Forschung und Technologie (BMFT) under contract number 05 345EA I and European Network contract number SCI-0471-C(A).

PERFORMANCE AND TUNING CHARACTERISTICS OF THE ENEA COMPACT FEL

F. Ciocci, A. Doria, G.P. Gallerano, E. Giovenale, M.F. Kimmitt, G. Messina, W.B.Case***

ENEA, Area INN, Dipartimento Sviluppo Tecnologie di Punta
P.O. Box 65, 00044 Frascati (Rome), Italy. Tel:+39-(6)-94001

Since 1992 a compact waveguide Free Electron Laser is operating at the ENEA Research Center of Frascati. At present it provides power up to 1.5 kW in 4 μs long pulses at wavelengths between 2.1 and 3.5 mm. A new undulator is under construction to extend the operating range down to 500 μm. The pulse duration will be increased up to 12 μs and the amplitude stability will be improved by using a 15 MW Klystron to drive the radio-frequency accelerator (5 MeV microtron).

Novel tuning characteristics have been observed, which depend on the dispersive properties of the waveguide resonator and on the bunched nature of the electron beam. Coherent emission occurs at harmonics of the 3 GHz radio-frequency in a band which is determined by the resonator length and finesse.

A comparison of the experimental results to a theoretical model is reported along with a description of a method for controlling the spectral bandwidth and pulse duration.

* Department of Physics, University of Essex, Colchester CO4 3SQ, U.K.
** Department of Physics, Grinnel College, Grinnel (Iowa), USA

A millimeter-range FEL experiment using the coherent synchrotron radiation emitted from electron bunches.

M. Asakawa, N. Sakamoto, N. Inoue, T. Yamamoto, K. Miira, and S. Nakai.
Institute of Laser Engineering , 2-6 Yamada-oka, Suita, Osaka
J. Chen, M. Fujita, K. Imasaki, and C. Yamanaka.
Institute for Laser Technology, 2-6 Yamada-oka, Suita, Osaka
N. Ohigashi, T. Agari, T. Asakuma
Kansai Univ., 3-10-1 Senriyama-higashi, Suita, Osaka
Y. Tsunawaki,
Osaka Sangyo Univ., 3-1-1 Daito, Osaka

This parer presents a free-electron-laser experiment using the coherent synchrotron radiation emitted from electron bunches. The rf linac used in our experiment delivers very short (5 ps) electron bunches. For the millimeter-wavelength, this bunch-length is shorter than the wavelength. In such case, the electron bunch acts like a single particle, and emits a strong coherent synchrotron radiation.

The energy of the electron beam was 6.85 MeV with a spread of 5 %. The peak current was 5 A and the macropulse-width was 2.5 μs. A planar wiggler of 6 cm period was used. The magnetic flux could be increased to 8.2 kG with narrowing the gap spacing. The number of periods was 10. To lengthen the resonant wavelength of FEL and to avoid the diffraction loss, the experiment was performed in the waveguide mode. The waveguide had the size of 6.5 mm × 13 mm and the length of 1 m.

The spontaneous emission was measured to be proportional to the square of the beam current. A peak power of 20 W was observed for the K-parameter of 3.95. A broad spectra from 1.5 mm to 4.0 mm was observed in this case. For the FEL oscillation, a pair of metallic mesh was used as resonator mirrors. A peak power of 16 W was observed at the wavelength of 2.73 mm with a narrow line-width of 3.6 %. The mechanism of this spectral selection can be attributed to the dispersion of the radiation in the waveguide. In the waveguide, only a spectral component which has a group velocity equal to the longitudinal electron beam velocity can be superimposed in a coherent way.

DEMONSTRATION OF ULTRAVIOLET LASING WITH A LOW-ENERGY ELECTRON BEAM*

P.G. O'Shea, S.C. Bender, B.E. Carlsten, J.W Early, D.W. Feldman, C.M. Fortgang,
J.C. Goldstein, B.E. Newnam, M.J. Schmitt, R.L. Sheffield, R.W. Warren,
T.J. Zaugg
Los Alamos National Laboratory
MS H825
Los Alamos, NM 87545, USA

23Mon

We report on the first ultraviolet (UV) lasing with an rf-linac-driven FEL oscillator. For a number of years we have advertised the benefits of photoinjectors as sources of bright, high-current electron beams. In particular, we have stated that the brightness of the electron beam from the APEX accelerator was sufficient for lasing in the UV at low electron beam energies[1]. The APEX accelerator was operated at 46 MeV, 120 A peak current and an unnormalized rms emittance of 200 nm. Essential to the success of the experiment were the fabrication of a permanent magnet wiggler of unusually short period (1.365 cm) and high magnetic field, and the use of resonator mirrors with unusual reflectivity characteristics. Lasing was achieved from a wavelength near 1 μm on the fundamental, down to 375 nm on the third harmonic. The 46 MeV electron beam energy is a factor of six smaller than that used for previous FEL lasing at similar UV wavelengths. In addition, we performed a proof-of-principle experiment which demonstrated the first ever photolithography on a silicon wafer using an FEL light source. We will report on the design details and performance of the UV FEL.

**Work funded by the Defense Programs Office of the US Department of Energy.*

1. "The Los Alamos POP Project: Design of FEL Experiments in the Ultraviolet and Beyond", B. E. Newnam, R.W. Warren, J.C. Goldstein, M.J. Schmitt, S.C. Bender, B.E. Carlsten, D.W. Feldman, P.G. O'Shea, Nucl. Instr. Meth A318, 197 (1992).

23Mon

EXPERIMENTS WITH GRATING-COUPLED FREE-ELECTRON LASERS

J.E. Walsh
Department of Physics & Astronomy
Dartmouth College
6127 Wilder Laboratory
Hanover, N.H. 03755-3528

A diffraction grating may be used to couple an electron beam with the electromagnetic field and thus as the basis of a free-electron laser. Spontaneous emission from electrons moving at near grazing incidence over a grating was first observed by Smith and Purcell[1] in 1953. These experiments were conducted with a low-current (10's μA), moderate-energy (200-300 kV) electron beam. Radiation in the visible wavelength region was produced using a grating with a grating period of 1.67 μm.

The radiation is produced by the surface current induced by the electron as it skims over the grating . The wavelength (λ), the emission angle (θ), the relative beam velocity ($\beta = v/c$), and the period of the grating (ℓ) are related by:

$$\lambda = \ell \; (1/\beta \; - \; \cos\theta) \tag{1}$$

When $\theta \rightarrow 0$, eq. (1) is essentially equivalent to the expression which relates wavelength, energy and undulator period in an FEL. When the beam is highly relativistic the wavelength of the radiation emitted at forward angles is much shorter than the grating period.

The addition of optical elements (*e.g.* a second grating) which provides sufficient feedback will lead to bunching of the electron beam and growth of the stimulated component of the emitted radiation. In this case, the device becomes a grating-coupled free-electron laser (G-FEL). Experiments with low-energy electron beams in the mm-wavelength region have demonstrated many basic features of this class of device. Recent[2] work with a relativistic electron beam has now also demonstrated the wide tuning capability in the FIR.

The presentation will contain a brief summary of G-FEL theory and a report on progress in experiments using the high-brightness photo-cathode RF injector on the Brookhaven National Laboratory Accelerator Test Facility (BNL-ATF).

1. S.J. Smith and E.M. Purcell, Phys.Rev. **92**, 1069, (1953).
2. G. Doucas, J.H. Mulvey, M. Omori, J.E. Walsh, M.F. Kimmitt, Phys.Rev.Lett. **69**, (1992).

COMMISSIONING FOR THE JAERI FEL SUPERCONDUCTING ACCELERATOR MODULES AND CRYOGENIC SYSTEM

E.J.Minehara, N.Kikuzawa*, R.Nagai, R.Kato, M.Sawamura, M.Takao, M. Sugimoto, M. Ohkubo, J. Sasabe**, Y. Suzuki and Y.Kawarasaki**

Free Electron Laser Laboratory, Tokai Research Establishment,
Japan Atomic Energy Research Institute
2-4 Shirakata-shirane, Tokai-mura, Naka-gun, Ibaraki-ken, 319-11
JAPAN
*Department of Nuclear Engineering, Kyushu University
6-10-1 Hakozaki, Higashi-ku, Fukuoka-shi, Fukuoka-ken, 812
JAPAN
**Hamamatsu Photonics Co., Research Center
Hamakita-shi, Shizuoka-ken, 434 JAPAN

Each module of the JAERI FEL superconducting accelerator is composed of a 500 MHz Nb cavity, double heat shields, slow and fast tuners, 3 higher order mode couplers, an adjustable main coupler, a shield cooler, a compact 4K He recondenser, their related peripherals and electronic instrumentations. All of the four modules were already installed in the JAERI FEL accelerator vault this January. The commissioning of the modules and cryogenic system, starting from the rf tests in the manufacture's factory and JAERI site at Tokai, up to the first operation is described.

23Mon

STUDY OF UNDULATOR INFLUENCE ON THE DYNAMIC APERTURE FOR THE DUKE FEL STORAGE RING

Y. Wu, V.N. Litvinenko, J. Madey

FEL Laboratory, Box 90319, Duke University, Durham, NC 27708-0319, USA

Abstract

The 1 GeV Duke FEL electron storage ring is dedicated to driving UV-VUV FELs in the 34-meter long straight section. The first undulator to be used in this storage ring is the OK-4 undulator. The influence of the OK-4 undulator on the dynamic aperture has been studied, and methods to increase the dynamic aperture in such a lattice is proposed. A new lattice suitable for a 26-meter long undulator is designed for future Duke FEL operations, and the dynamic aperture study on this lattice has been performed.

PERFORMANCE OF A MOPA LASERSYSTEM FOR PHOTOCATHODE RESEARCH

R.F.X.A.M. Mols and G.J. Ernst

University of Twente, Department of Applied Physics

P.O. Box 217, 7500 AE Enschede, The Netherlands

Abstract

A frequency doubled Nd:YLF laser system is described. Several aspects concerning energy and stability of the pulses will be discussed. The system consists of a CW ML Nd:YLF oscillator and two double pass amplifiers having a total small signal gain of about a million times which means care must be taken to prevent self oscillations. Due to saturation effects the energy per micro pulse is limited by 16 μJ, resulting in 4 μJ after second harmonic generation. For the frequency conversion KTP type II is used. The short term timing stability is measured using the a spectrum analyser and found to be less than 200 fs with a width of 450 Hz, the amplitude fluctuations over the 15 μs macro pulse are determined by the saturation behaviour of the amplifiers and the shot to shot stability of the amplifiers. At the moment the power supplies of the amplifiers are being improved as well a feed back will be installed to improve the energy depletion of the amplifiers. Also third harmonic generation is under study.

Mo3–07

23Mon

NUMERICAL INVESTIGATION OF A LASER GUN INJECTOR AT CEBAF*

S. Benson, J. Bisognano, P. Liger, H. Liu,
G. Neil, D. Neuffer, C. Sinclair, and B. Yunn
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23606-1909 USA

A laser gun injector is being developed based on the superconducting rf technologies established at CEBAF. This injector will serve as a high charge cw source for a high power free electron laser. It consists of a dc laser gun, a buncher, a cryounit, and a chicane. Its space-charge-dominated performance has been thoroughly investigated using the time-consuming but more appropriate point-by-point space charge calculation method in PARMELA. The notion of "conditioning for final bunching" is introduced. This concept has been built into the code and has greatly facilitated the optimization of the whole system to achieve the highest possible peak current while maintaining low emittance and low energy spread. Extensive parameter variation studies have shown that the design will perform beyond the specifications for FEL operation aimed at industrial applications and fundamental scientific research. Some potentialities have been found to make the design more cost effective.

* Supported by D.O.E. contract #DE-AC05-84ER40150 and Virginia Center for Innovative Technology.

23Mon

DYNAMIC CAVITY DESYNCHRONISATION IN FELIX

G.M.H. Knippels, R.J. Bakker, A.F.G. van der Meer, D.A. Jaroszynski, D. Oepts, and P.W. van Amersfoort

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie EURATOM-FOM
P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands

ABSTRACT

FELIX offers a unique combination of short electron bunches and long wavelength, i.e., a slippage parameter μ_c ranging up to 10. As a consequence there is a strong dependence of the small-signal gain, saturated power and micropulse duration on the cavity desynchronisation. A relatively large desynchronisation is needed to obtain a large gain, whereas a small desynchronisation is needed to obtain a high saturated power. It is, therefore, tempting to vary the desynchronisation *during the macropulse*, applying a large value during the first stage, and a small value when the laser approaches saturation. This also improves the stability of the laser output. In this paper we will give the first experimental proof of the feasibility of this technique. In a first exploratory experiment in April, we simultaneously achieved the high saturated power normally observed at very small desynchronisation, and the high gain normally observed at optimal desynchronisation. We achieved this by ramping the electron bunch repetition frequency by 4.5 kHz, rather than by moving the cavity mirrors.

23Mon

AMPLIFICATION OF SPONTANEOUS EMISSION WITH TWO HIGH-BRIGHTNESS ELECTRON BUNCHES OF THE ISIR LINAC

S. Okuda, J. Ohkuma, S. Suemine, S. Ishida, T. Yamamoto, T. Okada, and *S. Takeda

The Insitiue of Scientific and Industiral Research, Osaka University,
8-1 Mihogaoka, Ibaraki, Osaka 567, Japan
*National Laboratory for High-Energy Physics, 1-1 Oho, Tsukuba, Ibaraki 305, Japan

Free-electron laser (FEL) amplifier and oscillator experiments are being performed with high-brightness electron beams of the 38 MeV L-band linac at The Instiiute of Scientific and Industrial Research (ISIR). Recently, self-amplified spontaneous emission (SASE) from a single-bunch beam has been observed at wavelengths of 20 and 40 μ m. The maximum peak power of the radiation has been estimated to be 14 W for a wavelength of 40 μ m.

The purpose of this work is to amplify the SASE with aother electron bunch under an oscillator configuration. A gun pulser for generating two electron bunches at an interval of 37 ns which corresponds to the round-trip time of an optical cavity has been developed. The charge of the electrons in a bunch and the energy spread of the accelerated beam are 30 nC and 2%, respectively. These conditions are the same as those of the single-bunch beam used for the previous SASE experiments. The results for the experiments at a wavelength of 40 μ m will be reported.

Investigation of Microwave FEL with Reversed Guide Field

A.A.Kaminsky, A.K.Kaminsky, V.P.Sarantsev,
S.N.Sedykh, A.P.Sergeev, A.A.Silivra*

Particle Physics Laboratory,
Joint Institute for Nuclear Research,
141980 Dubna, Moscow Region, Russia

* *Physical Departament, Kiev University,*
252022, Kiev, Ukraine

The investigation of FEL in the 8-mm wavelength range is described. The principal features of FEL with reversed guide field in comparison to nonreversed guide field configuration, is discussed. The experiments on FEL with reversed guide field are described. The main attention is paid to the case of non-axis electron injection and FEL amplifier operation. To increase the efficiency of electromagnetic wave interaction, the wiggler field tapering is used in the last case. The obtained experimental data are compared with the theoretical predictions.

SLIPPAGE, NOISE AND SUPERRADIANT EFFECTS IN THE UCLA 10 μm FEL EXPERIMENT

P.Pierini, R.Bonifacio

Università degli Studi di Milano and INFN Sezione di Milano
Via Celoria 16, 20133 Milano - Italy

C.Pellegrini, J.Rosenzweig and G.Travish

Department of Physics, University of California Los Angeles, USA

We present the results of analytical and numerical calculations of the effects of noise, slippage and superradiance in the UCLA 10 μm FEL experiment, using a high brighness electron beam produced from a photocathode RF linac and a 1.5 cm period undulator. We compare the FEL evolution starting from noise and starting from an input signal. We can observe saturation and optical guiding effects, and we also show that a superradiant spike can be observed when starting from an external CO_2 laser signal. We also consider the possibility of studying harmonic production with a multiple wiggler scheme.

DESIGN OF A HYBRID FREE-ELECTRON LASER AMPLIFIER

Kazuyoshi Saito[1], Shigenori Hiramatsu[2], and Ken Takayama[2]

1 Graduate University for Advanced Studies at KEK
2 National Laboratory for High Energy Physics in Japan (KEK)
Tsukuba, Ibaraki, 305 Japan

Abstract

We have developed the ion-channel guided X-band free-electron laser(XFEL) which is a possible high power RF source for future linear colliders. Recently we attained the peak output power of 40MW with a 1.5MeV-400A electron beam injected from the induction gun; however, the saturation has not been observed because of several reasons. A certain way to achieve rapid FEL amplification with a relatively short wiggler distance is to employ driving beams modulated in longitudinal density at the same frequency as that of the FEL. This is a design study of the hybrid FEL consisting of the modulation system and XFEL. Essential features of a microwave FEL amplifier driven with bunched beams, which is a final scheme in a multi-stage FEL of the TBA/FEL, such as rapid phase following and sinusoidal gain evolution which have been theoretically predicted* will be realized in the hybrid FEL amplifier though it is less than perfect.

The beam modulating system consists of pre-bunching and idling cavities analogous to that of a klystron. The pre-bunching cavity is energized with an external magnetron or klystron and excited in TM_{010} mode. Interaction of slightly modulated beams with the idling cavity will lead to further modulation in the longitudinal direction. In the paper, beam loading in the pre-bunching cavity and beam-to-wakefield interactions in the idling cavity are discussed in detail by using an analytical approach and numerical simulations. Multi-particle simulations through the complex of devices(0.8kV or 1.6MeV induction guns, the modulating system, XFEL) taking account of magnetic beam guiding instead of ion-channel guiding have been performed. As a result, reasonable parameters for the beam modulating system and magnetic guiding system have been obtained; simulations show 30% density modulation requiring an input power of 100kW, stable transportation of beams more than 500A through the entire beam-line and power saturation with 50 MW. These results will be presented at the Conference.

* K.Takayama, *Phys. Rev. Lett.* **63**, 516 (1989).
K.Takayama, R.Govil and A.Sessler, *Nucl. Inst. and Meth.* **A320**, 587 (1992).

A FEM Section with Selective Feedback on the Basis of an External Resonator with an Echelette.

V.A.Bogachenkov
P.N.Lebedev Physical Institute, Leninsky Prospect 53,
117924 Moscow, Russia

The experimental results of [1], [2] confirm that it is possible to create narrow-band amplifier and generator circuits on the basis of free-electron masers(FEM) using smooth waveguides with external selective feedback as resonator structures. The feedback system, being external to the waveguide, permits easy tuning of its amplitude and frequency responses, which enables selection of the FEM operating band over a wide range of frequencies, limited only by the waveguide cut-off frequency .

The proposed FEM undulator section is based on the elements of external selective feedback used in the aforementioned works. It consists of a smooth cylindrical waveguide, the ends of which are joined to identical biconical horns having axial apertures for passage of the electron beam. The cylindrical front of the wave radiated by a biconical horn is transformed into a plane front by means of a two-dimensional parabolic mirror. This makes it possible to reverse the transformation of the plane wave front when introducing the radiation back into the FEM section, e.g., after its selection by elements of the external feedback system for subsequent amplification. Since both radiators are identical, it is possible to construct circuits of generators with circular resonator structures as well as circuits of forward-or backward-wave amplifiers in a FEM regime. A circular resonator is formed by echelettes and mirrors located externally to the radiators. In this manner, flexibility of construction is achieved in realizing various FEM circuits.

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Microwiggler generated on the Surface of PZT[Pb(Zr,Ti)O$_3$] Acoustic Waveguide using High Power Ultrasonic Waves

Jeong-Sik Choi, Chul-Ho So, Hun-Taek Chung, and Deuk-Ryoung Kim

Institute of Basic Sciences, Dongshin University,

Daeho 252, Chonnam 520-714, Korea

A new type of the electrostatic wiggler with a very short wiggler period λ_w is suggested in order that the electron beam with a relatively low energy ($\leq$ 50keV) emits the radiation in the submillimeter region of the spectrum. When a high power ultrasonic wave travels in a PZT[Pb(Zr,Ti)O$_3$] acoustic waveguide, a mechanical deformation occured in this piezoelectric body causes a separation of electric charges on the surface of PZT waveguide. Since the period and strength of the electric polarization depends on the frequency and power of a traveling ultrasonic wave, respectively, it is shown that the electrostaic microwiggler with the wiggler period $\lambda_w \simeq 0.4$ mm and $|Ew| \simeq 100$ keV/m may be generated from 10 MHz high power ultrasonic waves. This microwiggler on the surface of PZT acoustic waveguide could offer as the basis of an tunable and compact FIR free electron laser.

TWO COLOR FEL COMPLEX BASED ON HIGH CURRENT RACE-TRACK MICROTRON

E.B.Gaskevich, A.I.Karev, V.G.Kurakin

Department of High Energy Physics, Lebedev Physical Institute Leninsky Prospect 53, 117924 Moscow, Russia

Some schemes of two (multi) color FEL facility based on existing Lebedev Physical Institute Racetrack Microtron are proposed. The simultaneous use of electron beam of different energies from the same accelerator to drive different FELs allows to have picosecond trains of coherent light in far- and mid infrared region which are correlated in time and are independently tunable in frequency. It is shown that the race-track microtron is the most suitable driver for two (multi) color FEL in the case of considerably different wavelength light beams, because it has a number of electron beams with different energies easily available for extraction. The application program for such FEL complex is suggested. Tunability, high power level together with picosecond structure and two colors make such FEL complex unique for scientific applications. Some experiments for high T_c superconductors investigations are suggested.

A FREE ELECTRON LASER WITH ION-FOCUSSED DOUBLE UNDULATOR FOR VUV AND X-RAY GENERATION

A. V. Tulupov
FOM-Institute for Plasmaphysics "Rijnhuizen", Postbus 1207,
3430 BE Nieuwegein, The Netherlands

The use of an ion-focussing channel together with a double-period undulator enables to enhance the FEL gain greatly in the VUV and soft X-ray region. The mechanism of the gain enhancement lies in an additional bunching of the electron beam due to driven betatron oscillations. The amplitude of the driven oscillations is sensitive to the electron beam energy As a result the variation of the longitudinal electron velocity in response to a variation of the beam energy is increased as compared with a conventional FEL.

STATUS OF THE UCSB FREE-ELECTRON LASERS†

Gerald Ramian

Center for Free-Electron Laser Studies
Quantum Institute, University of California
Santa Barbara, CA 93106

The University of California at Santa Barbara (UCSB) currently has two fully operational FELs. These are dedicated to providing radiation for a scientific users' facility. The first of these machines covers a wavelength range from 2.5 millimeters to 340 μm, the second from 313 to 63 μm, and both represent a pioneering effort in providing tunable, coherent, high power radiation in the far-infrared portion of the spectrum.

A third FEL is designed to extend the range of wavelengths to 30 μm. This machine uses the same 6 MV electrostatic accelerator and is accommodated in a three position beam switchyard. This new FEL is unique in being designed to operate exclusively on the third harmonic. It uses the same high quality tunable undulator technology, developed at UCSB for the first two FELs, with a period of 1.85 cm and peak field of 6.5 KG. This and other details are discussed. One of the most difficult challenges has been suppression of fundamental lasing. Techniques developed for this purpose include grating, Michelson interferometer and a capacitive mesh frequency selective mirror.

Additional efforts are underway to extend time domain characteristics to the sub-nanosecond range, and to improve average linewidth, power, and duty cycle of all three machines.

† *The UCSB FEL facility has been developed and supported under various Office of Naval Research Contracts - currently N00014-92-J-1452*

Progress of the FELICITA I Experiment at DELTA*

D. Nölle, A. Geisler, M. Ridder, T. Schmidt, K. Wille
Institute for Acceleratorphysics and Synchrotronradiation
University of Dortmund
P.O. Box 500 500
4600 Dortmund 50, FRG
Fax: (FRG) 231-755-5383
email: Dirk at marvin.physik.uni-dortmund.de

FELICITA I, standing for **FEL In** a **CIrcular Test Accelerator**, is the first FEL experiment to be set up at the accelerator test facility DELTA at the University of Dortmund. Due to its low emittance and long straight sections this storage ring provides optimum conditions to realize FELs at wavelengths as short as 100 nm or even below. This goal of course cannot be reached within a single step. Thus the first FEL, a device with the possibility to be operated in two modes as a FEL or an optical klystron, will be more conventional and will operate in the visible and near UV.

After funding in October'92 a final design for the vacuum system and the undulator magnet have been made. Both components are under construction now, and will be completed at the end of the year. This is necessary as all the components, inserted into or connected directly to DELTA must be in place for the final assembly of DELTA, as they are needed to "close the ring". Thus, the commissioning of DELTA will take place with these components installed. During '94 also the 14 m optical cavity and the diagnostics will be set up. Following the actual time schedule, the assembly of FELICITA I should be completed till the end of '94.

*This work is supported by the Bundesministerium für Forschung und Technologie under contract 05 3PEAAI 0

STATUS OF THE COMMISSIONING OF THE SC LINAC LISA FOR THE 'SURF' FEL EXPERIMENT.

M. Castellano, M.Ferrario, M. Minestrini, P. Patteri, F. Tazzioli
INFN-LAboratori Nazionali di Frascati, C.P. 13, 00044 Frascati, ITALY

N. Cavallo, F. Cevenini
INFN- Sez.di Napoli and Dip.di Fisica, Università di Napoli, Pad. 20 Mostra d'Oltremare, 80125 Napoli, ITALY

F. Ciocci, G.Dattoli, A. DiPace, G.P. Gallerano, A. Renieri, E. Sabia, A.Torre
ENEA-CRE Frascati, Via E. Fermi, 00044 Frascati, ITALY

L. Catani
INFN - Sezione di Roma II, Via E. Carnevale, Roma, ITALY

The commissioning of injector of the superconducting linac LISA is completed. This stage is composed of a DC thermionic 100 keV gun followed by a chopper, a prebunching system and a room-temperature β-graded 1 MeV preaccelerator. A 180° arc brings the beam to the injection line on the SC cavity axis.

The results of power tests and rf conditioning of the sc cavities are presented.

Preliminary results on the beam acceleration in the sc linac, planned in early Summer, will be reported.

The OTR based diagnostic system will be described.

TWO FREQUENCY WIGGLER FEL OSCILLATOR :

SIDEBAND INHIBITION AND EFFICIENCY ENHANCEMENT

P. Chaix, D. Iracane, A. Bourdier
C.E.A. / PTN
91680 Bruyères-le-Châtel, France

Monochromatic radiation in high current FEL's is very unstable, due to sideban generation and mode coupling [1]. Although tapering has been found to inhibit sidebands in amplifiers [2], this is not true anymore for oscillators where a short time interaction is iterated a large number of times [3].

Numerical simulation suggests that an optimized space periodic modulation of the wiggler magnetic field, is able stabilize the laser dynamics, leading to a large increase of the extracted efficiency, with no sideband instability [4]. We interpret these results in terms of the electron dynamics : i) The trapping instability is inhibited because the resonance oscillates in phase space, so that the electrons follow chaotic trajectories. In particular, the optimized parameters of the modulation correspond to the maximization of the Lyapounov exponents. ii) The efficiency can be estimated via an analysis of the low signal gain and of the size of the stochastic area generated by the pulsating separatrix at saturation.

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CLOSURE RELATIONS IN MACROSCOPIC FEL EQUATIONS

G.H.C. van Werkhoven, T.J. Schep

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie Euratom-FOM
Postbus 1207, 3430 BE Nieuwegein, Nederland

The interaction between the electromagnetic field and the electron beam in a Compton-FEL is basically described by the wave equation and $2N$ electron equations of motion. The interaction may also be described by a system of macroscopic equations for a set of collective variables. A closure relation is required in order to truncate the series of moment equations.

The purpose of this paper is to obtain a closed set of equations which accurately describes basic features of FEL-interaction such as gain and saturation of the optical field but also phenomena like the generation of superradiant spikes and sideband modes which are due to the slippage between the optical and electron beam.

This problem has been investigated for a continuous electron beam in [1]. The closure relation proposed in that paper describes the exponential growth and the first few synchrotron oscillations of the radiation field but fails for longer times due to increasing differences in phase. Also the bunching due to the second harmonic of the ponderomotive phase is neglected.

Here, a set of equations is presented which is based upon a macro-electron approach. In this model the electron motion is divided into the motion of the bulk of the electrons in the ponderomotive bucket (the macro-electron) and a deviation. Several closure relations are investigated which are valid in different parameter ranges.

Solutions to both sets of equations will be presented. The validity of the closure relations and their effect on spiking and sideband phenomena will be analyzed by comparing the results of both models to the complete numerical solution.

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COMPUTER SIMULATION OF MODE EVOLUTION IN LONG PULSE FELS

Isidoro Kimel and Luis R. Elias
Center for Research in Electro-Optics and Lasers (CREOL), and Department of Physics, University of Central Florida, Orlando, Florida 32826

ABSTRACT

There are experimental indications[1] that long pulse FELs tend to operate single mode. On the theoretical side, as has been shown in a series of papers[2-6], this is to be expected since in FELs strong competition among modes takes place. In these papers the conclusions were reached on the basis of asymptotic stability analyses of the system of differential equations for the FEL mode dynamics. These studies were made by purely analytical means.

In the work reported here, instead of an asymptotic analysis, the mode evolution as a function of time, is obtained by solving numerically the system of nonlinear coupled differential equations derived for the mode dynamics. This allows us to follow the intensity growth of a number of modes, each one with its own gain and saturation parameters. It is seen that all the modes with positive effective gain start to grow exponentially. At the onset of saturation, the growth of all the modes starts to level off. Then, the intensity of the dominant mode saturates to a plateau, while the intensity of all the other modes decreases to zero. If the FEL is primed with a mode with less than maximum gain, that mode becomes dominant and its intensity suppresses the growth of the other modes. The result is that the FEL ends up operating single mode at the smaller-gain primed mode.

The system of coupled nonlinear differential equations describing the modes evolution, was obtained from a perturbation expansion of the basic equation for the FEL dynamics. The linear terms provide the small signal gain for the modes while the third order terms are responsible for the onset of saturation. The saturation terms are of two types. The diagonal terms represent the self saturation while the nondiagonal terms are responsible for crossed saturation. Through this crossed saturation the dominant mode suppresses the effective gain of the other modes. In general, the outcome of the competition depends on the ratio u=(crossed-saturat.)/(self-saturation). Strong competition systems with u>1 operate single mode. In long pulse FELs we have u=2, very strong competition and single mode operation.

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CHAOTIC ELECTRON TRAJECTORIES IN A HELICAL-WIGGLER FREE ELECTRON LASER

A. Bourdier*
C.E.A. / PTN
91680 Bruyères-le-Châtel, France

L. Michel-Lours
Laboratoire de Physique des Milieux Ionisés
Centre National de la Recherche Scientifique
Ecole Polytechnique, 91128 Palaiseau Cedex, France

The electron orbits in a helical wiggler are examined in the presence of a guide field. When the self-fields of the beam are taken into account, some trajectories become chaotic.

The nonintegrability of the electron motion is demonstrated in this work by calculating non-zero Lyapunov exponents. These are derived by using different approaches. The good agreement between the different results made us confident in the fact that, in some circumstances, a non-zero Lyapunov exponent exists.

Poincaré maps are also performed to confirm that some trajectories are chaotic. The results obtained are similar to those of C. Chen and R.C. Davidson [1].

Local Lyapunov exponents [2] are also calculated. The resulting mixing-time for the trajectories shows that the predicted chaos can be a proper problem in an experiment.

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* Also in Laboratoire de Physique des Milieux Ionisés, Centre National de la Recherche Scientifique Ecole Polytehnique, 91128 Palaiseau Cedex, France

INVESTIGATION OF MULTIFREQUENCY GENERATION IN THE FEM.

P.J. Eecen, A.V. Tulupov, T.J. Schep

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie Euratom-FOM Postbus 1207, 3430 BE Nieuwegein, Nederland

The FOM Fusion FEM [1] project involves the construction and operation of a 1-MW, 100ms pulse, rapid tunable FEM in the 130-250 GHz range for fusion applications. The undulator of the FEM consists of two sections with different strengths and different lengths separated by a gap without undulator field. The design provides arbitrary focussing.

Single frequency codes predict a much higher output power for the two-section undulator than for a one-section undulator. But the different undulator strengths lead to different resonance conditions and therefore in principle multiple frequencies can be generated. This problem of multi-frequency generation due to the two-section undulator has been investigated.

The longitudinal mode structure of the FEM is simulated in a multi-pass, multi-frequency code. In this code the electrons are described fully 3D, non-wiggle averaged and in the long pulse limit. AC longitudinal space-charge forces are included. The radiation field is considered to have the known transverse radial dependence of a HE_{11}-mode, due to the rectangular corrugated waveguide of the FEM.

[1] Urbanus et. al. *This conference.*

QUASI-OPTICAL THEORY OF THE FEL OSCILLATOR WITH CYLINDRICAL MIRRORS

Balakirev V.A., Ognivenko V.V.

The Ukraine Science Centre
Kharkov Institute of Physics & Technology, 310108, Kharkov, Ukraine

ABSTRACT

The theory of the FEL oscillator with planar undulator and quasi-optical resonator is presented. We are considered the interaction monoenergetic electron beam with wave beam formed by the cylindrical mirrors. Nonlinear equations of the beam particles motion and integral equations for the electromagnetic field in resonator are obtained. On the linear stage the eigenvalue problem is solved and we find the dependence of the growth rate and the start current from the parameters of the quasi-optical resonator. By the numerical methods nonlinear stage of the excitation of the radiation is investigated.

PRELIMINARY CONSIDERATIONS OF A FREE ELECTRON LASER OPERATING AT VERY LARGE μ_c

V.I. Zhulin*, R.J. Bakker, A.F.G. van der Meer,
D. Oepts, and P.W. van Amersfoort

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie EURATOM-FOM
P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands

ABSTRACT

The user facility FELIX employs a planar undulator of 247 cm length with 38 periods. The wavelength range is from 6.5 to 110 μm. The electron beam consists of a train of short pulses (3–6 ps) with a charge of 200 pC and an energy ranging from 15 – 45 MeV. In order to extend the operating range up to 300 μm with the same electron pulses it is necessary to change the undulator construction.

A 3-D simulation code, taking the time dependence of the distribution function of electrons into account, was used in order to compare the contribution of various physical processes (growth of slippage length with respect to electron pulse duration, increase in diffractional losses, waveguide effects) in the decrease in output power for long wavelength.

* Permanent address: State Optical Institute, St. Petersburg, Russia

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FELICITA II: A possible High–Gain FEL at the Storage Ring DELTA *

M. Ridder
Institute for Acceleratorphysics and Synchrotronradiation
University of Dortmund
P.O. Box 500 500
4600 Dortmund 50, FRG
Fax: (FRG) 231-755-5383
email: markus@marvin.physik.uni-dortmund.de

One main operation mode of the storage ring DELTA at the University of Dortmund will be the use as a FEL driver. High beam quality and long straight sections for the installation of undulators up to 14 m length make it an ideal facility for this purpose. In a first step the FEL experiment FELICITA I, designed to operate at 200–400nm will be set up. The next step will be the high-gain device FELICITA II, designed for wavelengths significantly below 100nm. The operation of such a device in the storage ring DELTA has been investigated using the 3-D FEL simulation code FELS.

The operation of a FEL below 100nm requires a high-gain device because of the poor reflectivity of available mirrors. To reach this goal optimization of all components of the FEL is necessary. Therefore, undulator parameters as well as electron beam parameters have been optimized. Also the influence of the FEL interaction on the design of an optical cavity and the effects of undulator errors and their correction have been investigated in detail.

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GAIN ENHANCEMENT IN GAS-LOADED FEL

L.A. Gevorgian

Yerevan Physics Institute
Alikhanian Brothers 2, Yerevan 375036, Armenia

ABSTRACT

The radiation of electrons in FEL below the Cherenkov threshold is investigated. It is shown that the gas-loaded FEL gain is inverse proportional to the fifth power of electron energy. The presence of medium allows to generate photons with given frequency by electrons with lower energy. Using medium with certain gas density longitudinal distribution determined by the electron energy losses along the trajectory one can provide the synchronism condition along all the FEL. The gain increases along the trajectory. All these facts results in the essential growth of the intensity of produced photons. If the technical difficulties will be overcome one can achieve almost full energy transformation into radiation energy.

NUMERICAL ANALYSIS OF RADIATION BUILD UP IN FEL OSCILLATOR

Shin-ichiro KURUMA, Masahiro NARUO*, Kunioki MIMA*, Sadao Nakai* and Chiyoe YAMANAKA

Institute for Laser Technology,
2-6 Yamadaoka, Suita, Osaka 565 JAPAN
*Institute of Laser Engineering, Osaka University,
2-6 Yamadaoka, Suita, Osaka 565 JAPAN

Using one-dimensional multi-frequency simulation code, it is investigated how the radiation build-up time in FEL oscillator depends upon the electron beam micro pulse length.
By the simulation, it is found that in the case when the electron beam micro pulse length is shorter than the radiation wavelength, the radiations in the cavity build up faster than the other case. (So it is called coherent spontaneous emission.)
The effect of cavity length detuning on radiation build-up in FEL oscillator is also investigated. The out-put radiation power is found to be very sensitive to the detuning. When the cavity Q-value is given, the full detuning width for the half maxima is $\Delta L=\lambda s/4Npass$ for radiation wavelength λs and pass number Npass.

A SELF CONSISTENT ANALYSIS OF BUNCHING AND HARMONIC GENERATION IN FREE ELECTRON LASER

G. Dattoli, L. Giannessi, P.L. Ottaviani* and A. Torre
ENEA, INN.SVIL, P.O. Box 65, 00044 Frascati (RM), Italy

The Free Electron Laser (FEL) dynamics is a rather intrigued interplay among bunching, emission, high order bunching and saturation. The phenomenology associated to the self-induced bunching is extremely interesting: it is, indeed, associated to the coherent harmonic generation.

We present a general procedure to understand the evolution of FEL dynamics, including self-bunching and harmonic generation. We exploit a formalism based on the Liouville equation which is extended to the case of pulse propagation and transverse mode dynamics. We also discuss the problems associated to FEL behaviour when the system operates with a suitably prebunched electron beam.

(*) ENEA, INN.SVIL, Divisione Calcolo, Bologna, Italy.

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HYBRID RESONATORS FOR FELS

Isidoro Kimel and Luis R. Elias
Center for Research in Electro-Optics and Lasers (CREOL), and Department of Physics, University of Central Florida, Orlando, Florida 32826

ABSTRACT

For long wavelength FELs with linear polarization, hybrid resonators have proven to be quite useful. They allow for the usually conflicting requirements of small undulator gap and, at the same time, low radiation losses in the resonator. To have a high Q resonator is essential for a two-stage FEL since the power stored in the first stage can be extremely high.

These resonators support hybrid (semigaussian) radiation modes which are guided in only one of the transverse directions, while behaving according to Hermite-Gaussian functions in the other transverse direction, x say. In the y direction the modes behave as sine functions. This behavior is enforced by cylindrical resonator mirrors.

In the past, hybrid modes have been studied in Cartesian coordinates in the paraxial approximation[1]. Although many of the mode characteristics can be obtained in that way, there are things that are difficult to do in Cartesian coordinates, like applying boundary conditions at the cylindrical mirrors, for instance. This is particular important when calculating the amount of radiation outcoupled through mirror slits or holes.

In the work reported here we study hybrid modes in the system of coordinates which is most natural for the geometry of the hybrid resonators, namely the Elliptic-Cylinder (EC) system of coordinates. This system contains only one Cartesian-like coordinate (y) which is taken perpendicular to the guiding horizontal walls. The other two coordinates are curvilinear, on horizontal planes the EC coordinates are θ and η parametrizing hyperbolas and ellipses. All hyperbolas and ellipses have in common a pair of foci separated by a distance $2a$. This focal distance a turns out to be essentially equal to the Rayleigh length z_R. The hyperbolas are ideal for describing beams focused to a waist at some transverse plane.

Instead of the paraxial approximation, the full wave equation in EC coordinates is solved. Since in these coordinates the Helmholtz equation is separable, two transverse and one longitudinal equations are analyzed. In terms of the scalar solutions, the vectorial fields are obtained taking the appropriate derivatives according to the Whittaker prescription. The resonator mirrors coincide with coordinate surfaces which are also radiation phase fronts. Thus, the solutions obtained are the eigenmodes of the cold resonator.

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A CONFOCAL RING RESONATOR FOR THE CEBAF INFRARED FREE ELECTRON LASER

Stephen V. Benson, Hongxiu Liu, and George Neil
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23606-1909 USA
(804)249-5026
(804)249-7352-fax

and

Ming Xie
Center for Beam Physics
Lawrence Berkeley Laboratory, Berkeley, CA 94720

We report on the cold and warm cavity behavior of a confocal ring resonator for the proposed infrared FEL at CEBAF the resonator will consist of two spherical mirrors separated by their radii of curvature and a third kicker to deflect the return mode to the side so that the return beam does not have to go back through the narrow wiggler bore. This design takes advantage of the degeneracy of the confocal cavity in order to get an optical mode which is small in the wiggler, large in the return leg, and insensitive to angular misalignments of the mirrors. The cold cavity diffractive losses at long wavelengths are calculated and the minimum size of the apertures in the resonator are determined. The warm cavity modes at short wavelength are calculated and the sensitivity to gain variations is studied. The sensitivity of the laser mode to angular misalignments and mirror radius of curvature changes is determined. The resonator can be easily modified so that it is a confocal unstable resonator or a stable-unstable resonator.

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MEASUREMENT AND CORRECTION OF MAGNETIC FIELDS IN PULSED SLOTTED-TUBE MICROWIGGLERS*

C. M. Fortgang and R. W. Warren
Mail Stop H825
Los Alamos National Laboratory
Los Alamos, NM 87545

Pulsed electromagnetic microwigglers are capable of creating stronger fields with shorter periods than conventional wigglers. Wiggler field parameters of typically 1 Tesla and 5-mm period are achieved by passing ~25 kA down a slotted 3 mm-diameter copper tube. The taut-wire technique is used in a small aperture (~1.5 mm) to measure the wiggler magnetic fields with the required spatial (~0.1 mm) and temporal (~5 μs) resolution. The absence of midplane symmetry, in contrast to permanent magnet wigglers, causes unique problems in our microwigglers. We have measured strong dipole (bending) and quadrupole (defocusing) field errors with both dc and time-dependent parts. The effect of current redistribution on the magnetic field due to heating in the copper tube has been measured. We have identified causes for the various field errors and their sensitivities to fabrication tolerances. Improvements we have made towards meeting the required tolerances and our field-correction technique will be discussed.

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3D MAGNETIC FIELD WIGGLER ANALYSIS FOR A FEL-BASED BUNCHING EXPERIMENT

J.GRENIER, J.GARDELLE, J.L.RULLIER

C.E.A./C.E.S.T.A., PO Box 2, 33114 LE BARP, (France)

In the framework of the CLIC proposal, we are developing a test facility to measure the longitudinal bunching occuring in a high gain FEL[1]. The 1-2.5 MeV, 1 kA electron beam delivered by the LELIA induction linac is transported with coils into a hybrid planar wiggler where it will interact with a 35 GHz copropagating wave. We describe here wiggler studies.

A 8 cm, 8 periods hybrid planar wiggler mock-up was designed for trajectographic studies. It consists of NdFeB magnets, measured with Helmoltz coils and numerical ordered to minimize errors, and soft iron parabolic poles to be self-focusing[2].

We have developed a three-axis magnetic field measurement sensor, with a high mechanical precision bench, using high quality, NMR calibrated, Hall probes. Acquisition is fully automatic and permits to easily obtain the three wiggler field components in function of the three axis. Fringing field at wiggler entrance has been extensively study and a system to cancel the first and second field integral is shown. Calculations with 2D and 3D magnetostatic codes are given and agree very well with measurements. Transverse focalisation is studied for different gaps and gives the range in B_w permitted.

Preliminary results on LELIA electron beam trajectories inside the wiggler are presented.

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IN-VACUUM TYPE UNDULATOR FOR VISIBLE/UV REGION FEL USING LINAC

T.Keishi, A.Kobayashi, and T.Tomimasu
FREE ELECTRON LASER RESEARCH INSTITUTE, INC.(FELI)
2-7-4, Kyomachi-bori, Nishi-ku, Osaka 550 Japan

T.Okazaki and Y.Hosoda
Electromagnetic Application Systems R&D Department
SUMITOMO ELECTRIC INDUSTRIES, LTD.
1-1-3, Shimaya, Konohana-ku, Osaka 554 Japan

FEL facility covering from 20 to 0.2μm using a 170MeV S-band RF linac is under construction at FREE ELECTRON LASER RESEARCH INSTITUTE, INC. Four undulators operated by four different electron beam energy are used to cover above region. Conventional Halbach type undulators are used to produce IR region FEL. In-vacuum — permanent magets are placed in a vacuum chamber — type undulator is necessary to produce visible/UV region FEL. The design, fabrication of an undulator(one meter long) for testing, achievement of ultrahigh vacuum with bakeout process for evacuation, and magnetic field measurement before and after bakeout process are reported. The parameter and conceptual view of the undulator are shown in Table 1 and Fig. 1, respectively.

Table 1. Parameter of in-vacuum type undulator

Permanent magnet material	NdFeB
Permanent magnet size	$5 \times 10 \times 50\text{mm}^3$
Period	2cm
Number of period	50
Minimum gap	5mm
Peak magnetic field	0.85T
Maximum K	1.58

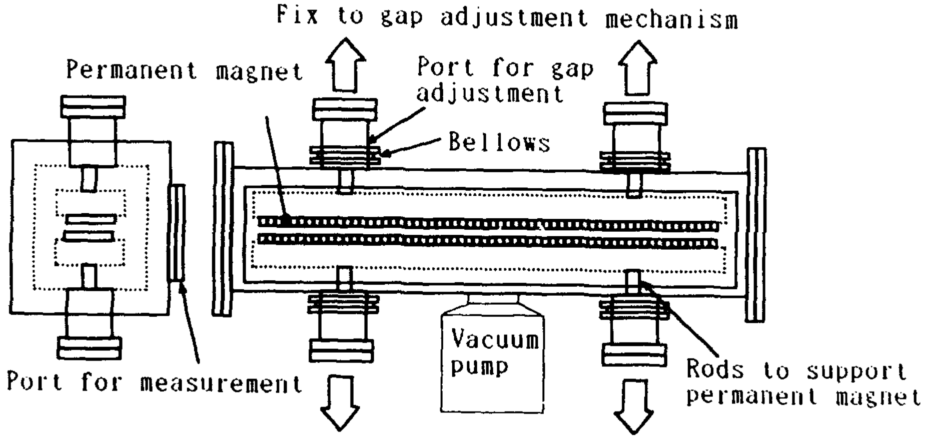

Fig. 1. In-vacuum type undulator

DEVELOPMENT OF ELECTROMAGNETIC HELICAL MICROWIGGLER

N.Ohigashi, K.Mima[1], Y.Tsunawaki[2], S.Ishii[3], N.Ikeda[3], K.Imasaki[4], M.Fujita[4], S.Kuruma[4], A.Murai[5], C.Yamanaka[4] and S.Nakai[1]

Faculty of Engineering, Kansai University, Suita, Osaka 564, Japan. [1]Institute of Laser Engineering, Osaka University, Suita, Osaka 565, Japan. [2]Faculty of Engineering, Osaka Sangyo University, Nakagaito, Daito, Osaka 574, Japan. [3]Mitsubishi Heavy Industries, Ltd.,Wadasaki-cho, Hyogo-ku, Kobe, Hyogo 652, Japan. [4]Institute for Laser Technology, Suita, Osaka 565, Japan. [5]Co-experimenter of Institute of Laser Engineering, Osaka University, Suita, Osaka 565, Japan.

A core type electromagnetic helical microwiggler was developed which have three poles in a periodic length and the structure is shown in Fig.1 and 2. The same size hexagonal permendur cores having a pair of magnetic poles on a diagonal line located the magnetic pole gap in the center part, are rotated by 120 degree in every one of the core sheets①,②,③,...(Fig.1), and accumulated them succesively in one direction(Fig.2). The six coils are wound in every side of the hexagon, and they are wound as in surrounding the whole cores. The polarities of the six magnetomotive forces by the six coils are inversely applied alternately in every neighboring coil. The periodic length is 6.6mm, the magnetic field strength is 5kG(K=0.3), the gap length by a pair of the magnetic poles is 4.6mm, the magnetomotive force by one coil is 1830ATurn. Propagating the electron beam with energy of 6MeV into this wiggler, the oscillation wavelength of few tens μm is obtained by FEL operation. This structure has the merits of the least leakage magnetic field between succesively neighboring poles in the core type microwiggler, and equal repetition of the field distributions in every period. At present, we have been measuring the magnetic field distributions by the threefold-enlarged trial wiggler of the same structure.

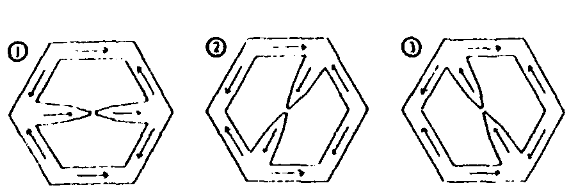

Fig.1

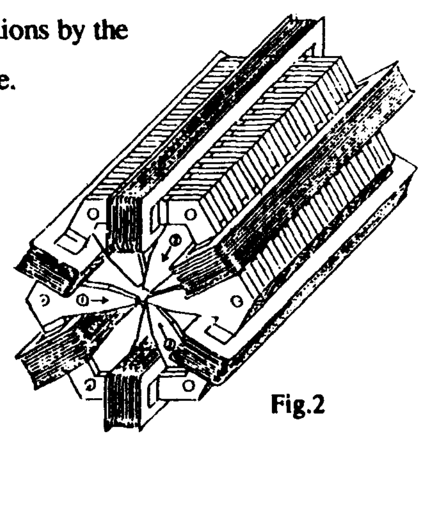

Fig.2

HIGH INTENSITY RACETRACK MICROTRON AS FREE ELECTRON LASER DRIVER

V.G.Kurakin

Department of High Energy Physics, Lebedev Physical Institute Leninsky Prospect 53, 117924 Moscow, Russia

Racetrack microtron combines best features of classical microtron and linac that makes it very attractive for many applications in wide range of energies and currents, free electron laser being in the list of possible applications. At the same time some features of beam cavity interaction inherent to such accelerator put limit to electron beam current and power. The beam intensity have been reached so far at Lebedev Physical Institute racetrack microtron (250 mA of pulse current at 30 MeV) to be used for infrared radiation complex consisting of several lasers is limited by its modulation above definite threshold. It is shown that this modulation originates from positive feedback arising at some frequencies in the system rf cavity - electron beam. Beam - cavity interaction equation followed by stability analysis are presented. Linear approximation is used to derive stability conditions, the latter being represented in analytical form followed by numerical calculations and stability diagrams. The obtained results are compared with experimentally measured values showing validity of used conception of beam cavity interaction and accepted simplifications. Physical sense of observed intensity modulation as well as some measures of their suppression are discussed.

INITIAL PERFORMANCE OF THE UCLA RF PHOTOINJECTOR GUN

N. Barov, P. Davis, G. Hairapetian, S. Hartman, M. Hogan, C. Joshi
S. Park, C. Pellegrini, J. Rosenzweig, G. Travish, R. Zhang
UCLA Department of Physics
405 Hilgard Ave
Los Angeles, CA 90024, USA

An rf photocathode gun which, along with a ...ct linac, forms the injection system for a planned 10 μ... free-electron laser amplifier experiment, has been commisioned in the Particle Beam Physics Laboratory at UCLA. This high-gradient gun, based on the Brookhaven design, has emitted several picosecond, >100 A electron beams of up to 4 MeV in energy. These beams have been characterized by a variety of diagnostics. The quantum efficiency of the copper cathode used has been measured at normal incidence, and at 70 degrees incidence, where the polarization dependence was also examined. Limits on laser intensity due to surface damage, and to longitudinal space charge suppression of photoemission have been explored. The energy and energy spread of the beam were characterized using a dipole spectrometer, while the time structure was examined using a picosecond resolution streak camera. Both energy spread and pulse length were found to be adversely effected by longitudinal space charge forces. The emittance of the beam was measured using the pepper pot technique, and its dependence on space charge and rf phase were found. The impact of these results on improving the design and operation of high brightness photoinjectors is discussed, in particular with respect to SASE FEL amplifiers such as the UCLA 10 μm FEL, and the proposed SLAC x-ray FEL.

PROPOSED PARTICLE-BEAM CHARACTERIZATIONS FOR THE APS UNDULATOR TEST LINE*

Alex H. Lumpkin, Michael Borland, and Steve Milton
Advanced Photon Source
Accelerator Systems Division
Argonne National Laboratory
9700 S. Cass Avenue, Argonne, IL 60439 USA

At the Advanced Photon Source (APS), a research and development effort is underway using an rf gun as a low emittance electron source for injection into the 100-to-650 MeV linac subsystem and subsequently to an undulator test area. This configuration would combine the acceleration capability of the 200-MeV s-band electron linac and the in-line 450-MeV positron linac that normally provide positrons to the positron accumulator ring (PAR). A transport line that bypasses the PAR will bring the electrons to the undulator test area. The system is projected to produce an electron beam with a normalized, rms emittance of $<10\pi$ mm mrad at micropulse charges of up to 350 pC.[1] Characterization and preservation of the low-emittance beam will be critical to the undulator tests. Particle-beam emittance measurements will be done using a three-screen technique over a 10-m drift space as the baseline method with optical transition radiation interferometry (OTRI) and variable quadrupole field, single-screen techniques as complementary. The micropulse bunch length (~5 ps, FWHM) will be measured using a synchroscan streak camera operating at 117 MHz and viewing the beam's interaction with an OTR foil. Beam position monitors will be based on a series of stripline pickups and associated electronics. Tests proposed include measurement of particle transport effects caused by small undulator field errors as well as operations intended to produce coherent short wavelength radiation (<200 nm).

1. M. Borland, "An Improved Thermionic Microwave Gun and Emittance-Preserving Transport Line," Proceedings of the 1993 Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-Eng-38.

ELECTRONS GENERATED BYAN uv EXCIMER LASER

V. Nassisi

University of Lecce, Department of Physics
National Institute for Nuclear Physics, Lecce-I

Abstract.

Using an XeCl excimer laser (4.02 eV), a focusing lens and a suitable acceleration chamber, electrons were provided by metal cathodes. In this work Zn cathodes, which present a work function of about 3.6 eV, was used in order to produce electrons. The plasma formed on the cathode surface influences the electron emission. In fact, using short laser pulse (10 ns) the electron pulse shape was similar to that of the laser pulse, whereas using a wider pulse (15 ns) an increase of the electron emission at the laser pulse tail was observed.

It was studied the electron emission as a function of the laser density on the cathode varying the distance of the lens from target. About 5 A/cm^2 current density was obtained with a 13 mJ laser energy. Besides, this result was compared with these obtained by other metals having an higher and a lower work function.

The emission current was measured by a small Rogoskwi coil working as a transmission line.

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Superradiant Start Up of a Short Pulse FEL Oscillator

D.A. Jaroszynski, D. Oepts, A.F.G. van der Meer, R.J. Bakker and P.W. van Amersfoort

FOM-Instituut voor Plasmafysica "Rijnhuizen", Association Euratom - FOM, P.O. Box 1207, 3430 BE Nieuwegein, Netherlands

Abstract

We present the first experimental observation of coherent enhanced start up of a free electron laser (FEL) oscillator due to the superradiant (SR) nature of spontaneous emission resulting from a combination of a short duration electron bunch and a long resonance wavelength. We have measured the absolute value of the SR enhanced start up intensity, as high as 3 to 5 orders of magnitude below saturation of the FEL, and measured its wavelength dependence which is related to the Fourier transform of the electron bunch shape. We have also observed, experimentally, that, as a consequence of the excellent stability of the accelerator, interference effects cause the SR emission intensity to be partially suppressed or enhanced depending on the exact optical cavity length ie. depending on the discrete longitudinal cavity mode. We also present cross correlation measurements of the SR enhanced spontaneous emission which show that coherence between adjacent optical micropulses is already well established at start up of the FEL. Finally, we present spectral measurements of the spontaneous emission which show an enhanced broadening that is consistent with the SR start up of the FEL. Because of the short bunch length and the long wavelength of FELIX, SR enhanced emission occurs over almost the whole range of its operation.

Comparison between a FEL amplifier and oscillator

P. Zambon, W.J. Witteman
University of Twente
Department of Applied Physics
P.O. Box 217
7500 AE Enschede, The Netherlands
and
P.J.M. van der Slot
Nederlands Centrum voor Laser Research B.V.
P.O. Box 2662
7500 CR Enschede, The Netherlands

Previous experiments with the Raman FEL, situated at the Twente University, showed that the output was influenced by the rather strong increase of the current density with time [1]. The field emission diode has been modified to produce a more constant current pulse to simplify the analysis of the measurements. This resulted in a lower current density of the electron beam.

With this new diode two setups are studied. In the first setup the laser is still configured as an amplifier [2] whereas in the second setup the laser configuration is changed into an oscillator. The reduced current density makes it necessary to use an oscillator configuration to obtain high power levels. The oscillator is built by using a Bragg reflector with a space-variable corrugation height [3]. With such a reflector it is possible to provide good mode selectivity. For both setups we measure the total energy in the radiation pulse using a Joule meter [1] and for specific values of undulator and guide magnetic fields the frequency spectrum.

The relative performance of the amplifier and the oscillator configuration will be presented together with the influence of the Bragg reflector on the behaviour of the laser.

[1] P.J.M. van der Slot, PhD thesis, University of Twente, 1992

[2] P.J.M. van der Slot, W.J. Witteman, Energy and frequency measurements on the Twente Raman FEL. To be published in Proceedings of the fourteenth International FEL conference, Kobe, Japan 1992

[3] P. Zambon, P.J.M. van der Slot, Design of a 30 GHz Bragg reflector for a Raman FEL. Presented at this conference.

23Mon

HIGH-POWER CYCLOTRON AUTORESONANCE MASER(CARM) EXPERIMENTS[1]

J.L.Rullier[2], S.Alberti[3], B.G.Danly, E.Giguet[4],
G.Gulotta, T.Kimura, W.L.Menninger, and R.J.Temkin
Plasma Fusion Center,
Massachusetts Institute of Technology,
Cambridge, MA 02139

Abstract

CARMs are attractive sources for applications such as electron cyclotron resonance heating (ECRH) of fusion plasmas and driving high gradient RF accelerators.

For ECRH applications oscillators in the 140-280 GHz range with high average power (>1MW) are required. A 28 GHz long-pulse (1μs) CARM oscillator experiment has been carried out at the MIT Plasma Fusion Center. A 450 keV, 80 A electron beam is generated by a diode Pierce gun. The interaction takes place inside a Bragg resonator. Output power of 1.9 MW (efficiency of 5.2%) has been measured in the TE_{11} mode. A significant mode competition between the TE_{11} and a TM_{01} is present.

For applications such as accelerator drivers, amplifiers or locked-oscillators at frequencies in the 11-33 GHz range with high peak power (>100MW) are required. A 17 GHz short-pulse (50ns) CARM amplifier experiment is also underway. This device utilizes the SRL/MIT SNOMAD II linear induction accelerator injector for production of a beam at 400 keV and 400 A. The source of the signal is a magnetron, and the amplifier is designed to operate in the TE_{11} mode. Theoretical and experimental results on CARM gain, efficiency, and rf phase stability will be presented.

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[1] Supported by the Department of Energy, Advanced Energy Projects Office, under contract DE-FG02-89ER14052. Additional support from Science Research Laboratory, DARPA, and LLNL is gratefully acknowledged.

[2] Supported by CEA/CESTA, France.

[3] Supported by Swiss National Science Foundation, Fellowship Nr. 8220-30665.

[4] Also with Thomson Tubes Electroniques, Vélizy, France.

STUDY OF WAVEGUIDE MODE IDENTIFICATION IN FEL EXPERIMENT

K.Sakamoto, M.Shiho, S.Musyoki, A.Watanabe and Y.Kishimoto
Japan Atomic Energy Research Institute, Naka Fusion Research Establishment, Naka-machi, Ibaraki-ken, Japan 311-01
S.Kawasaki
Saitama Univ. Facility of Sci. 255 Shimo-okubo, Urawa 388, Japan
H.Ishizuka
Fukuoka Inst. of Tech. Wajiro, Higashi-ku, Fukuoka 811-02, Japan

A wavenumber spectrometer(k-spectrometer[1]) was applied to determine and identify exactly the mode of the FEL radiation in Raman regime. An intense electron beam of 1MeV and 300A generated with the inductive acceleration unit LAX-1 of JAERI, amplified the input rf pulse of 200W up to 6MW in the frequency of 45GHz, in the course of transport through the focusing planar wiggler. A spatial growth rate of 56dB/m, and a total gain of 52dB were observed for fundamental mode TE_{11}(circular). The higher modes of the radiation in the amplification process, however, were not identified therein and therefore the detailed comparison of the experimental results with the conventional FEL theory still remains rather open to question. It is first necessity to know the spatial growth of each mode separately for understanding of the FEL interaction mechanism of the intense beam in Raman regime. Results of the mode measurement will be compared with the numerical calculation obtained using 3D multi-waveguide mode interaction code, where the beam space charge effect is fully introduced.

[1] W.Kaspareck, G.A.Mueller, Int.J.Electronics,**64**,5-20(1988).

23Mon

DESIGN ELEMENTS FOR A FEL OPERATING IN THE VUV

F. Ciocci, G. Dattoli, A. De Angelis, F. Garosi,
L. Giannessi, P.L. Ottaviani* and A. Torre
ENEA, INN.SVIL, P.O.Box 65, 00044 Frascati (Rome), Italy

We present the design elements for a FEL operating in the VUV (below 100 nm) and exploiting a new concept based on an oscillator-triplicator scheme. The key idea underlying the design is that to realize a device consisting of two parts:

a) In the first, called modulator, a high quality e--beam from a linac drives a FEL oscillator in the region of excimer lasers. The FEL interaction produces coherent radiation and e-beam bunching.

b) In the second part, called triplicator, the e-beam is extracted and injected into an undulator whose resonant frequency is just the third harmonic of the oscillator. The bunching occurring in the modulator is sufficient to provide start-up and final growth in the triplicator.

We discuss the technological problems underlying this FEL concept and the laser performances.

(*) ENEA, INN.SVIL, Div. Calcolo, Bologna, Italy.

Mo4–20

23Mon

GENERATION OF HARMONICS USING THE MULTI-CAVITY FEL

Srinivas Krishnagopal
Centre for Advanced Technology
Indore 452013, INDIA

and

Andrew M. Sessler*
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

An FEL provides a convenient method of reaching short wavelengths by resonating with an input source at the fundamental wavelength while providing bunching at a harmonic of the fundamental. Recently schemes have been proposed that use two wiggler segments, one resonant at the fundamental, to pre-bunch the beam, and the other lasing at the desired (third) harmonic [1]. A similar effect, with some advantages and some disadvantages, can be achieved using the Multi-Cavity FEL (MC/FEL). The MC/FEL employs several short cavities, operating in an oscillator-like manner, to achieve high output power [2]. In this paper we consider the use of the MC/FEL as a means of generating harmonics. We investigate the competitiveness of this option, in comparison with other harmonic generation schemes, in terms of the total wiggler length needed, the saturated power achieved, and the restrictions imposed by mirror reflectivity.

[1] R. Bonifacio et al, Nucl. Instr. and Meth. **A296**, 787 (1990); R. Prazeres and J.M. Ortega, Nucl. Instr. and Meth. **A296,** 436 (1990).

[2] S. Krishnagopal and A. Sessler, "Stability of Resonator Configurations in the Presence of Free-Electron Laser Interactions", to be published in Optics Communications; S. Krishnagopal et al, "Numerical Studies of the Multi-Cavity Free-Electron Laser", to be published in Nucl. Instr. and Meth.

*Supported by the US Department of Energy, Division of High Energy and Nuclear Physics, under Contract No. DE-AC03-76SF00098.

THE PROJECT OF HIGH POWER FREE ELECTRON LASER USING RACE-TRACK MICROTRON-RECUPERATOR

G.I. Erg, N.G. Gavrilov, E.I. Gorniker, G.N. Kulipanov, I. V.Kuptsov, G.Ya. Kurkin, A.D. Oreshkov, V. M. Petrov, I.V. Pinayev, V.M. Popik, I.K. Sedlyarov, T.V. Shaftan A.N. Skrinsky, A.S. Sokolov, V.G. Veshcherevich N.A. Vinokurov, and P.D. Vobly

Budker Institute of Nuclear Physics

11 Lavrentyev Ave., Novosibirsk, 630090, Russia

Tel: 7-(3832)-359977 Fax: 7-(3832)-352163

Email: vinokurov@inp.nsk.su

Abstract

The high power free electron laser is under construction in the Novosibirsk scientific center. The goal of this project is to provide the user facility for especially organized Siberian Center of Photochemical Researchers.

The features of installation and the project status are discussed.

23Mon

BEAM CONDITIONING IN STORAGE RING DRIVEN FEL

V.N.Litvinenko

FEL Laboratory, Box 90319, Duke University ,Durham, NC 27708-0319, USA
Telephone: (919)-660-2658; Fax: (919)-660-2671, e-mail: vl@phy.duke.edu

Abstract

The short wavelength performance of a storage ring driven FEL is limited by horizontal emittance. A natural vertical emittance in a storage ring is usually a few orders of magnitude lower than horizontal emittance. Thus, only horizontal emittance conditioning is essential.

The method of beam conditioning to cancel emittance contribution to the longitudinal velocity spread was proposed in [1].

The linear and second order correlations between horizontal betatron oscillations and electron energy are studied. The possibility to use different correlation terms (for example, "fast phase oscillations") for beam conditioning is considered. A microwave RF-system and mm-wavelength FEL are examined as possible candidates for a conditioning scheme.

The importance of high longitudinal dispersion in FELs (for example in optical klystrons) for beam conditioning is discussed.

OPERATION OF A SMALL INFRARED FEL SYSTEM FOR RESEARCH AND STUDENT TRAINING

J. M. J. Madey and K. D. Straub
FEL Laboratory, Box 90319, Duke University
Durham, NC 27708-0319

The MkIII infrared FEL system has been operated for five years as a research tool, light source and student training facility. A variety of modifications and upgrades have been carried out during these years to improve its capabilities and reliability. We have also tried to determine the operational and organizational factors most relevant to maintenance of high productivity. We will review our recent operational experience at this facility and our plans for the future.

23Mon

PROGRESS OF THE IR FEL DEVELOPMENT AT JAERI

M.Sugimoto, M.Takao, M.Sawamura, R.Nagai, R.Kato, N.Kikuzawa+, E.J.Minehara, M.Ohkubo, Y.Kawarasaki, and Y.Suzuki

Free Electron Laser Laboratory, Japan Atomic Energy Research Institute
Tokai, Ibaraki 319-11, Japan

+ *Department of Nuclear Engineering, Kyushu University*
Fukuoka, Fukuoka 812, Japan

The JAERI infrared FEL development program is under the final construction phase. The program aims to confirm the quasi-cw oscillation of IR FEL (10-40 μm) using the superconducting accelerator. It is a prototype of the advanced facility for technological purposes. The four superconducting accelerator modules are installed and rf tests are carried out. All modules attained the design specification of the acceleration field: 5 MV/m with Q-factor $\gtrsim 2\times10^9$. The beam transport lines among the accelerator modules and that for guiding to the undulator section are also installed with the vacuum equipments. Status of the performance tests of each component will be reported.

Mo4–30

23Mon

FAR-INFRARED CAPABILITIES AT THE VANDERBILT UNIVERSITY FREE-ELECTRON LASER CENTER

Perry A. Tompkins, Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, and John Walsh, Department of Physics and Astronomy, Dartmouth College, 102 Wilder Hall, Hanover, NH 03755.

The Vanderbilt University Free-Electron Laser Center is presently incorporating an experiment to provide far-infrared(FIR) to sub-mm radiation for users. A collaboration between Dartmouth College and Vanderbilt University has been formed to accomplish this. Dartmouth College has extensive experience creating this type of radiation using slow-wave interaction structures of both the Cerenkov and Smith-Purcell type[1]. The present goal of this experiment is to create and transport to the laboratory broad-band, spontaneous FIR light using a Smith-Purcell slow-wave structure. Eventually the experiment should provide intense, coherent FIR laser light in the 50-200 μm regime using a slow-wave structure coupled with an appropriate resonator. This paper will describe the experiment being assembled at Vanderbilt. The useful parameter space has been investigated computationally and will be discussed. Additionally, a brief section will be included to cover the theory necessary to understand the interaction and predict the expected performance.

[1] G. Doucas, J. Mulvey, M. Omori, M. F. Kimmitt, and J. Walsh, Phys Rev Lett, 69,1761,1992.

Three-Dimensional Codes for Simulating *e*-Beam Transport and FEL Operation Including Space-Charge Effects

Y. Pinhasi, M. Cohen and A. Gover

Dept. of Electrical Engineering - Physical Electronics
Faculty of Engineering, Tel-Aviv University,
Ramat-Aviv, 69978, Israel

Abstract

Three-dimensional models, which describe the electron beam transport and electromagnetic interaction in a FEL are presented. The models are based on single particle force equations, and take into account emittance and space-charge effects in the *e*-beam, and transverse spatial variation in the radiation field.

In the electron beam transport problem, a cylindrically symmetric transverse density distribution is assumed, with any azimuthal and radial angular spread. The particle trajectories are obtained by solving numerically the equation of motion for a general magnetic field in the presence of space-charge forces. The parameters of the particles in the beam are then displayed in real space and phase space. We demonstrate simulation of the the particle transport for a Gaussian distribution in the transverse space and in the momentum coordinates.

In the FEL model, the total electromagnetic field (including the RF space-charge field) is expanded in terms of normal modes of the waveguide (including the cut-off modes). The field interaction with the *e*-beam is described by the force equation for electrons and a set of EM excitation equations for the waveguide modes. Such a model takes into account 3-D effects of the radiation and space-charge fields, and thus provides a complete description of the FEL interaction for any kind of symmetry of the *e*-beam and waveguide cross-sections. The equations are solved numerically to simulate FEL operation in the nonlinear Compton or Raman regimes.

COMPUTER SIMULATION OF MICRO-CHERENKOV FEL OSCILLATOR

Toshihiro Taguchi and Kunioki Mima†
Department of Electrical Engineering, Faculty of Engineering,
Setsunan University, Neyagawa, Osaka, 572, Japan
†Institute of Laser Engineering, Osaka University,
Suita, Osaka, 565, Japan

Abstract

Computer simulation of micro-Cherenkov free electron laser oscillators composed by a field emission array (FEA) and a micro-dielectric waveguide has been done using particle simulation code. We calculated temporal and spacial evolutions of motion of electrons and radiation field amplitude in a micro-dielectric cavity. We will show the one-path gain and the oscillation start-up time calculated by the code. We will also discuss the requirement for the beam current and the quality of the FEA beam to produce a sufficient output power.

NUMERICAL COMPUTATIONS ON THE ENTROPYLIKE QUANTITY OF THE EQUILIBRIUM ELECTRONS IN A COLLECTIVE FREE-ELECTRON LASER *

Shi-Chang Zhang, Qingxang Liu and Yong Xu

Department of Applied Physics, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

Abstract

Nonlinear computations of the entropylike quantity are given to the equilibrium electrons in a collective free-electron laser with positive or reversed guide field. Results indicate that the quality of the electron beam in the case of reversed guide field may be better than the one in the case of positive guide field. However, the quality of the beam is spoiled at the antiresonance. The conclusions in the point of view of the entropylike quantity principally coincide with the experimental phenomena observed by the MIT researchers.

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* Project supported by the NNSFC.

LONGITUDINAL BEAM COMPRESSION IN FREE-ELECTRON LASERS*

B. Hafizi[+,a)] and C. W. Roberson[#]

[+]Beam Physics Branch, Naval Research Laboratory
Washington, DC 20375-5346, USA
[#]Physics Division, Office of Naval Research
Arlington, VA 22217, USA

Longitudinal compression of an electron beam, such as subharmonic bunching, increases the current. An increase in the current enhances the growth rate of a free-electron laser (FEL). However, since phase space density is conserved, longitudinal compression is accompanied by an increase in the energy spread on the beam, which tends to reduce the growth rate. Based on our kinetic analysis of an FEL[1,2], we have investigated the effect of beam compression on the growth rate, filling factor, efficiency and curvature of the radiation wavefronts. It is found that the growth rate increases with beam compression as long as the interaction is in the cold-beam regime. That is, provided the scaled thermal velocity S $\equiv \beta_{th,z}/\langle\beta_z - \beta_{ph}\rangle$ is less than unity. Here, $\beta_{th,z}$ is the axial velocity spread on the beam, β_z is the axial velocity of an electron, β_{ph} is the phase velocity of the ponderomotive wave and $\langle...\rangle$ indicates the mean over the electron distribution. An improvement in the growth rate by a factor ~ 2 is the best that we have obtained by compressing the beam in a number of examples. The peak improvement in the growth rate occurs when S ~ 1, decreasing with further increase in the compression.

a)Icarus Research, 7113 Exfair Road, Bethesda, MD 20814, USA

1. B. Hafizi and C. W. Roberson, Phys. Rev. Lett. 68, 3539 (1992)
2. C.W. Roberson and B. Hafizi, in Proc. 14th. Intl. FEL Conf., Kobe (1992)

*Supported by ONR

THE EFFECT OF A WIGGLER ON CYCLOTRON MASER INSTABILITY

G. Mishra*

ENEA, Area INN, Dipartimento Sviluppo Tecnologie di Punta
P.O. Box 65 - 00044 Frascati, (Rome) Italy. Tel:+39-(6)-94001

The cyclotron resonance maser instability is studied for a tenuous relativistic electron beam in the presence of a longitudinal wiggler and an axial magnetic field. An analytical expression for the growth of the instability is obtained for the case of non-fundamental cyclotron harmonic operation. It appears that, depending on the beam and wiggler parameters, substantial enhanced growth rate can be obtained in comparison to that of a standard electron cyclotron maser

* Permanent address: School of Physics, DAVV, Indore, 452001, INDIA

Mo4–42

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Time-dependent behavior of a short-pulse FEL

J.K. Lee, S.J. Hahn, E.H. Park, and T.H. Chung*
Pohang Institute of Science and Technology
Pohang, Kyungbuk 790-600, Korea

One-dimensional time-dependent FEL equations are used to investigate the nonlinear short-pulse propagation. The spiking behavior is related to the superradiant pulse propagation and its dynamical regimes are closely correlated to the bifurcation and the chaotic transition in the nonlinear dissipative dynamics[1]. The synchrotron slippage length plays an important role in determining the dynamical regimes. With cavity detuning parameter, *slippage parameter*, and *superradiant parameter*, we describe the bifurcation and the chaotic transitions via period-doubling cascade, intermittency, and quasiperiodicity. The real-time signal, phase space plot, and the corresponding FFT spectrum are used to confirm our results. The space charge effects[2] are also included as the electron beam current is varied.

* Dong-A University, Pusan, Korea

[1] S.J. Hahn and J.K. Lee, Nucl. Instr. Meth. (to be published); Phys. Lett. A (to be published); Phys. Rev. E (submitted).

[2] T.H. Chung, et al., Nucl. Instr. Meth. (to be published); H.S. Kim, et al., J. Phys. Soc. Japan (to be published).

THE SIMPLE MODEL OF THE SUPERMODES IN FEL WITH AN INTRACAVITY ETALON

V.M. Popik and N.A. Vinokurov

Budker Institute of Nuclear Physics
11 Lavrentyev Ave., Novosibirsk, 630090, Russia
Tel.: 7-(3832)-359977 Fax: 7-(3832)-352163
Email: popik@inp.nsk.su

Abstract

The influence of intracavity glass plate with parallel planes on characteristics of FEL is theoretically investigated. For the given thickness of the plate the minimum of lasing linewidth is calculated. The decrease of FEL gain with an intracavity etalon and the losses connected with imperfection of the plate are estimated. The theoretical results are compared with results of the VEPP-3 Optical klystron on the narrowing of lasing line width.

AN INFRARED GRATING FREE-ELECTRON LASER*

B. Hafizi[a)], P. Sprangle[b)] and A. Fisher[b)]

A nonlinear model of a grating free-electron laser, including the effects of self-field forces, beam emittance, energy spread and gyromotion in a guide field, is described. The radiation is generated by the passage of an annular electron beam through a coaxial pair of conductors, the central conductor being in the form of a corrugated cylinder. Interaction of electrons with the space-harmonics of such a slow-wave structure has the potential for a high-power and relatively narrowband source of radiation. Design parameters for a compact, low-voltage infrared grating laser will be presented.

a) Icarus Research, 7113 Exfair Road, Bethesda, MD 20814, USA
b) Plasma Physics Division, Naval Research Laboratory, Washington, DC 20375, USA

* Supported by ONR

FEL GAIN DEPENDENCE ON THE LONGITUDINAL DISTRIBUTION OF THE ELECTRON BEAM DENSITY IN THE PRESENCE OF BEAT WAVES

A.G. Shamamian

Yerevan Physics Institute
Alikhanian Brothers 2, Yerevan 375036, Armenia

ABSTRACT

The expression for the gain of FEL in which high current electron beam interacts with laser beat waves is obtained. In case of gaussian distribution the gain has its maximum near the relativistic plasma frequency of the beam. For the frequencies much higher than plasma frequency the gain decreases exponentially. In case of asymmetric gaussian distribution the gain decreases. It is proposed to use asymmetrically distributed electron beams interacting with laser beat waves to produce intense radiation in the submillimetric region.

ABOUT THE SCHEME OF FEL WITH SYNCHRONIZING MAGNETIC FIELD FOR BEAM COOLING AND OPERATION WITH HOT BEAMS

S.A.Mikheev
Russia Scientific Center "Kurchatov's Institute"
123182 Moscow, Russia

In [1] the scheme of a FEL for operation with "hot" electron beams was suggested. Two various aproaches are possible: the turn of electrons on the plane of electron undulator oscillations (a) and the turn on the transverse plane (b). There is no difference between two schemes within the framework of one-dimensional model (the energy and the phase). In the present work the influence of the average on the fast-varying phase and the suggestion that the longitudinal velocity is constant are analyzcd. At different conditions, especially for a powerful electromagnetic wave, the results of the calculations for two cases are not the same: the scheme (b) is more preferable. In the small signal regime the scheme (b) is more perspective for high efficiency of amplification, the results are not much distinguished from the results of [1]; the scheme (a) is more preferable for the beam cooling [2] (decreasing of energetic dispersion).

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MONOCHROMATIZATION OF THE FEL RADIATION BY THE SYSTEM OF THE BOUND RESONATORS

V.I.Alexeev, E.G.Bessonov, M.L.Vnukova

Lebedev Phys. Inst. of the Russian Academy of Sciences, Moscow, Russia

The monochromatization of the parametric free-electron laser radiation by the system of the bound resonators have been studied.

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Dispersion Characteristics of Electromagnetically Pumped FEL

T.H.Chung

Dept. of Physics, Dong-A University, Pusan 604-714 Korea

J.K.Lee

Dept. of Physics, Pohang Institute of Science and Technology
Pohang, Kyoungbuk 790-600, Korea

Abstract

We solve the dispersion of the scattered radiation for the electromagnetically pumped Free-electron laser and investigate the dispersion characteristics of the scattered radiation by calculating the growth rate for various operating schemes. We formulate the one-dimensional coupled Maxwell Lorentz equations and perform the particle simulation of the performances of FEL amplifier and compare with analytic results. We discuss the requirements on the electron beam quality and parameter regime of practical interest.

HOLE-COUPLED CONFOCAL RESONATORS FOR X-RAY GENERATION VIA INTRACAVITY THOMSON SCATTERING*

Ming Xie and Kwang-Je Kim
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720, USA.

ABSTRACT

It has been shown in our previous studies** that the behavior of a hole-coupled symmetrical confocal resonator is quite different from that of other resonators. The optical mode in a confocal resonator is capable of avoiding the diffraction losses through the holes on the cavity mirrors and simultaneously improving the filling factor for higher FEL gain when possible. In this paper we investigate the hole-coupled confocal resonator for X-ray generation via Thomson scattering inside an FEL oscillator. The use of a confocal resonator with holes on the mirrors serves the purpose of coupling electron beam through and X-ray out of the cavity, while supporting the FEL mode with minimal diffraction loss. We discuss various resonator configurations including the ring geometry and analyze their performance taking into account the diffraction and FEL gain medium.

* This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under contract No.DE-AC03-76SF00098.

** M. Xie and K.-J. Kim, Nucl. Instr. and Meth. in Phys. Res., A304, p792, 1991; A318, p877, 1992; and "Hole-coupled Resonators for Broadly Tunable Infrared Free Electron Lasers", Proceedings of OE/LASE'93, Los Angeles, California, Jan. 16-23, 1993.

PLASMA TREATMENT OF DIELECTRIC-COATED CAVITY MIRRORS FOR SHORT WAVELENGTH FEL

K.Yamada, T.Yamazaki, N.Sei, and T.Mikado

Electrotechnical Laboratory
1-1-4 Umezono, Tsukuba City, Ibaraki 305, Japan
TEL:298-58-5679, FAX:298-52-7944

In storage-ring free-electron lasers, extremely low-loss cavity mirrors are usually required because of their low gains in principle. In addition, the irradiation of mirror surfaces by higher harmonics of the undulator radiation causes the significant increase of mirror losses through the deposition and/or doping of carbon atoms onto the mirror surfaces. This is particularly true in short wavelength regions, because a higher ring current is required to compensate for the low gain. In order to restore the mirror reflectivity, RF-plasma-induced radicals were applied to the surfaces of the degraded mirrors. The apparatus for the RF-plasma treatment and the loss-measurement system will be presented. The experimental results will be discused.

UNDULATOR MAGNETIC FIELDS MEASUREMENTS WITH WIRE DEFLECTION METHOD.

A.A.Varfolomeev, A.S.Khlebnikov, N.S.Osmanov, S.V.Tolmachev.
Coherent Radiation Laboratory, Russian Research Center
'Kurchatov Institute', Moscow 123182, Russia

Abstract

As first experiments with pulsed wire method (see for example [1]) did show it could be very promising for operative control of undulator magnetic fields. To achieve read-out of the wire transverse displacement during short wire current pulse outlined devices contained a rather complex and expensive optical detector unit. It was one of the disadvantages of these schemes.

We describe in this paper a pulsed-wire design with very simple and reliable read-out unit which provides good results (without using laser beam or microscope). A 280-V short current pulse is directed through a thin 100 μm in diameter beryllium-copper wire placed along the axis of the wiggler. Weight equal to 120 g provides sufficient wire tension. The detection system consist of fast optical detector with a triangular entrance window crossed by the wire. The detector voltage output is a linear function of wire displacement with the sensitivity equal to 1.3 mV/μm .

The outlined device was tested and used for magnetic field measurements of the KIAE-4 undulator and some its mock-ups [2] . To estimate the accuracy of the new device measurements of the first and second magnetic field integrals were made with the wire method as well as with Hall probes usually used for precise measurements of the undulator fields. It was found that the wire method gives the second integral of the field with accuracy 5%. The higher accuracy is possible with an improved electronic unit.

During the above measurements it was shown that not only wiggling oscillation of the electron beam can be simulated by the wire method but also β-oscillations of the electron beam in the undulator field. The appropriate β-oscillation current wire deflections were revealed using the same set-up with 90° turned detector system.

References

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[2] A.A.Varfolomeev, S.N.Ivanchenkov, A.S.Khlebnikov, N.S.Osmanov, M.J.van der Wiel, W.H.Urbanus and V.F.Pavluchenkov. KIAE-4 undulator design for FOM FEM project. Preprint IAE-5600/14, 1993. RRC 'Kurchatov Institute', Moscow, Russia.

PERFORMANCE OF THE KIAE-4 UNDULATOR FOR THE FOM FEM PROJECT

A.A.Varfolomeev, S.N.Ivanchenkov, A.S.Khlebnikov, N.S.Osmanov
Coherent Radiation Laboratory, Russian Research Center 'Kurchatov Institute', Moscow 123182, Russia
M.J. van der Wiel, W.H.Urbanus
FOM Institute for Plasma Physics 'Rijnhuizen', 3430 BE Nieuwegein, The Netherlands
V.F. Pavluchenkov
D.V.Efremov Scientific Research Institute of Electrophysical Apparatus
St.Petersburg 189631, Russia

Abstract

A special hybrid undulator KIAE-4 has been designed for the FOM FEM project [1]. It provides strong magnetic fields for relatively high ratio of gap to period 0.625 along with transverse magnetic field profiles for electron beam focusing. Two sections of the undulator contain 20 and 14 periods respectively with the period length equal to 4 cm. Both sections are mounted on a base frame. The system enables to change intersection distance between sections from 40 mm to 80 mm.

Each section appears as plane hybrid undulator magnet arrays supplied by two additional side magnet arrays. The usual upper and lower magnet arrays are made from Sm_2Co_{17} magnet blocks interspaced with vanadium permendure poles. The side magnet arrays are pure permanent magnet $SmCo_5$ systems. The main magnet fluxes of both array systems being added result an enhancement of the on-axis magnetic field By. The side array magnets provide also focusing parabolic field profiles.

Position of any permanent magnet can be adjusted separately. Together with special shunting plates it enables the fine tuning of the magnetic field strength and its profile as well. With this procedure the transverse focusing strength is adjustable in rather wide range.

Each undulator section contains also the entrance and exit cells for longitudinal matching of the magnetic fields. For small corrections of e-beam trajectory in the experiment two electromagnet coils are placed in the intersection gap.

The nominal magnetic field amplitudes on z-axis equal to 2.0 kGauss for the first section and 1.6 kGauss for the second one respectively. The field amplitude spread is less than 0.25 %. The presented results of the magnetic field measurements of the tuned undulator show that the KIAE-4 undulator is fully adequate to the project [1].

Reference

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THREE DIMENSIONAL GAIN ANALYSIS OF FEL USING A FOCUSING UNDULATOR WITH ALTERNATELY SHIFTED PERMANENT MAGNETS

Yoshiaki TSUNAWAKI[a], Nobuhisa OHIGASHI[b], Kunioki MIMA[c], Shin-ichiro KURUMA[d], Kazuo IMASAKI[d], Masayuki FUJITA[d], Akira MURAI[e], Chiyoe YAMANAKA[d], and Sadao NAKAI[c]

a) Dept. of Electrical Engineering and Electronics, Osaka Sangyo University, Daito, Osaka 574, Japan
b) Department of Physics, Kansai University, Yamate-cho, Suita, Osaka 564, Japan
c) Institute of Laser Engineering, Osaka University, Yamada-oka, Suita 565, Japan
d) Institute for Laser Technology, Yamada-oka, Suita, Osaka 565, Japan
e) Cooperator of Institute of Laser Engineering

In the previous work[1], the propagation properties of electron beam have been studied on undulators consisting of circularly or parabolically curved magnets, trapezoid/rhomboid shaped magnets or alternately shifted magnets. The gain of the FEL using these geometrically focusing undulators has been also estimated by a one dimensional simulation code. In this procedure, it was only calculated for electrons propagating in the undulating (X-Z) plane where the magnetic field did not have both components of Bz and Bx.

In order to perform a more detailed analysis, a three dimensional simulation code has been developed for FEL with a focusing undulator and a Fabry-Perot type optical resonator in this work. It was, furthermore, applied to the gain analysis of FEL using an alternately shifted magnet undulator.

1)Y.Tsunawaki et al.: Nucl. Instrum. Meth. Phys. Res. A304 (1991) 753. ibid (1993).

FIRST OPERATION OF A SHEET-BEAM, FEL AMPLIFIER*

V. L. Granatstein, W. W. Destler, Z.X. Zhang, J. Rodgers, B. Levush, T.M. Antonsen, Jr., and D. Chen

University of Maryland, College Park, MD 20742

The sheet beam FEL amplifier with a short-period, linear wiggler magnet has been proposed as a millimeter-wave source for current profile modification and/or heating of Tokamak plasmas; such an amplifier would have an output frequency of ~100 GW, output power of 1-10 MW cw, and operate at a modest level of voltage. To test important aspects of this concept, we have performed an experiment using a sheet beam (1mm$\times$ 2cm) produced by a pulse line accelerator ($\tau \sim$ 100 ns). A 500 keV, 6A beam is propagated through a 56 period uniform wiggler (λ_w = 9.6mm) with peak field of 5 kG. Linear amplification of a 10W, 94 GHz signal injected in the TE_{01} rectangular mode is observed. All features of the amplified pulse including its width, peak power and detailed shape are in accordance with the predictions of numerical simulation. Absorption of microwave power at times just prior to the start of amplification is observed. Continuation of this experiment will involve adding a section of tapered wiggler and studying nonlinear amplifier operation.

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Experimental mode analysis of a circular free electron laser

Takahide Mizuno, Takashi Ohtsuki*, Tsutomu Ohshima, and Hirobumi Saito

Institute of Space and Astronautical Science
3-1-1 Yoshinodai Sagamihara, Kanagawa, Japan
TEL: 427-51-3911 (3367), FAX: 427-58-5041
**) Musashi Institute of Technology*

Coherent microwave and millimeter wave emission from a rotating electron beam in a circular wiggler magnetic field (circular free electron laser) has been studied. The circular wiggler which consists of a coaxial waveguide and an azimuthally periodic magnetic field is compact as compared with a conventional liner FEL. Tunable radiation frequency was observed to be typically 11- 38GHz using a mildly relativistic electron beam with energy less than 500kV, about 300A current and about 8μs pulse width. The total radiation power is about 840kW at Ku band radiation.

In accordance with the measurement of the frequency spectrum, we determine the oscillation mode of the superradiant circular FEL. The radiation frequency was measured with a YIG Filter (band width 15MHz) and a band-pass filter system (band width 100MHz). Narrow frequency spectra have been observed in Ku band (lower mode) and Ka band (higher mode). The FWHM of the frequency spectra in the lower mode radiation were less than 30MHz. Every measured frequency almost agrees with the theoretical cutoff frequency of the TM (p, 1) mode in the coaxial waveguide. In addition, the far field radiation pattern from the circular FEL was measured, in order to determine the oscillation mode. In Ku band, the measured pattern of which frequency was 11.5GHz (+/- 0.25GHz) agrees with the theoretical far-field radiation pattern of TM (8,1) mode. We discuss details of circular FEL operation by means of these oscillation mode analysis.

RESEARCH ON AND WITH FELIX

A.F.G. van der Meer and the FELIX team

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie EURATOM-FOM,
P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands
Telephone + 31 3402 31224

The past year has been devoted primarily to the operation of FELIX as a User Facility, but a substantial fraction of the beam time has been used to optimize the performance and to carry out a research programme on FEL-physics. In this paper we discuss the present performance (in terms of spectral range, output power, tunability, etc.) and present an overview of the results of our FEL-physics programme. Among these is the observation of superradiant start-up of the laser, and the selection of single-mode radiation from the FELIX output. Further, we present the first experimental results on the laser performance when the cavity desynchronism is varied during the macropulse. We will also give an overview of experiments carried out by users.

FEL EXPERIMENT ON THE UVSOR STORAGE RING

H. HAMA, J. YAMAZAKI and G. ISOYAMA
UVSOR Facility, Institute for Molecular Science, Myodaiji, Okazaki 444, Japan

Free electron laser (FEL) experiments are in progress on the UVSOR electron storage ring. The first lasing was achieved at a visible wavelength of 456 nm, as reported at the FEL conference last year. We will present the results of further investigations that have been made since then.

The period of the macro-pulse profile of laser light is shorter than the radiation damping time of the electron beam. We have applied the Q-switching technique to control lasing. However, large enhancement of the peak output power was not observed. To understand a time dependent behavior of the storage ring FEL, we have measured temporal profiles of the micro pulses of the laser and the electron bunch.

Recently we began to use a higher harmonic RF cavity (HC) in the FEL experiments in order to enhance the gain. The HC is operated such that the slope of the accelerating field becomes steeper, and the bunch length becomes shorter. The bunch length is reduced to ~ 60 % of the normal value even at higher beam current and therefore the gain becomes ~1.7 times higher.

Experiment in the ultraviolet region is also under way, in which the electron energy is maintained at 500 MeV and the K-value of the undulator sections is reduced. The estimated gain at wavelengths longer than 300 nm is comparable to that of 450 nm region. When mirrors at 340 nm were exposed to undulator radiation, the reflectivity around 350 nm went down in a very short time, which was not observed for mirrors at 460 nm.

24Tue

MEASUREMENT OF ENHANCED LONGITUDINAL OPTICAL MODES FROM A PHASE LOCKED FREE-ELECTRON LASER

Eric B. Szarmes, Angus D. Madden,
and John M. J. Madey

Department of Physics, Duke University,
Durham, NC, USA 27708

Mailing Address: Duke University,
Free-Electron Laser Laboratory,
Box 90319,
Durham, NC USA 27708-0319

ABSTRACT

We have measured the spectrum of longitudinal optical modes from an rf linac free-electron laser in which successive optical pulses are coupled by an intracavity Michelson interferometer. The coupling induces temporal phase coherence between successive pulses which is manifest in the frequency domain as a reduction in the number of modes per rf frequency interval. By externally filtering a single rf band in the optical spectrum, we measured mode power enhancements of greater than a factor of three; these enhamncements were limited in the present experiments by optical damage to the intracavity beamsplitter coating. In a separate experiment, we coupled successive pulses using an uncoated dielectric interface, and observed a 42 % reduction in the outcoupled power due to destructive interference of the phase locked optical pulses at the beamsplitter; this measurement compares with a 48 % reduction predicted by theory. We describe the experimental apparatus, present the results of the spectral measurements, and suggest improvements for future experiments.

POWERFUL CHERENKOV MICROWAVE AMPLIFIERS AND GENERATORS WITH RELATIVISTIC EXPLOSION-EMITTED ELECTRON BEAMS

E. Abubakirov, N. Kovalev, N. Zaitsev

Institute of Applied Physics
603600 Nizhny Novgorod, Russia

ABSTRACT

Use of high-current electron amplifiers with explosion emission injectors in powerful microwave devices is constrained by the requirements that the efficiency and spatial coherence of the output radiation be high. These requirements limit the size of the transverse cross-section of the interaction space and in amplifiers their efficiency as well. The amplification coefficient in relativistic amplifiers is also limited by a high noise level of explosion emitted electron beams.

The paper discusses possible ways to perform mode selection in generators and to achieve sufficiently strong amplification in Cherenkov amplifiers working on explosion-emitted electron beams. It is shown that in the long-wave part of the millimeter wavelength band, and, especially, in the centimeter wavelength band the most powerful and efficient devices are those of the Cherenkov type, in which the electrons moving rectilinearly interact with slow electromagnetic waves. The results of experiments on generation of pulsed high-frequency radiation with power over 1 GW and amplification of pulse signals to 200 MW are presented. Experiments on phasing two independent relativistic amplifiers and investigation of mutual coherence of radiation of two autogenerators are described.

WIGGLER IMPERFECTIONS IN FREE-ELECTRON LASERS*

H.P. Freund† and R.H Jackson
Code 6840, Vacuum Electronics Branch
Naval Research Laboratory, Washington, D.C. 20375
Phone: 202-767-0034; FAX: 202-767-0082

A self-consistent three-dimensional analysis of wiggler field errors in free-electron lasers is described using the WIGGLIN simulation code [1]. WIGGLIN treats the electron dynamics by integration of the complete 3-D Lorentz force equations, and does not rely on a wiggler-averaged formalism. The three-dimensional planar wiggler model chosen is able to treat gradients in the wiggler amplitude since both the divergence of the field and the axial component of the curl vanish identically while the transverse components of the curl are small. Hence, the field model is well-suited to the treatment of small imperfections in the wiggler amplitude. In order to describe the wiggler imperfections, a random variation is chosen to determine the pole-to-pole variations in the wiggler amplitude and a continuous map is used between the pole faces. The average efficiency, as well as the standard deviation about the average efficiency, is determined by using an ensemble of different randomly chosen wiggler variations with a fixed rms variation. The specific parameters chosen for study correspond to the high-power 35-GHz ELF free-electron laser experiment conducted at Lawrence Livermore National Laboratory [2]; however, the fundamental phyics issues are relevant to the entire range of free-electron laser experiments. On average, increases in the rms value of the field imperfections cause a decrease in the interaction efficiency; however, this is relatively benign and is certainly a much less severe constraint than that imposed by electron beam quality considerations. In addition, particular error distributions can result in efficiency enhancements.

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†Permanent Address: Science Applications International Corp., McLean, VA, 22102, USA.

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PULSED WIGGLER-PULSED TAPER FOR HIGH-EFFICIENCY RESONATOR

H. Leboutet
c/o CEA/SPTN
B.P. N° 12, 91680 Bruyères-le-Châtel, FRANCE

ABSTRACT

One way to attain high efficiencies with an oscillator requires to modify the profile of the wiggler during the build-up time (a few microseconds) of the oscillation*. This implies that the inductances are small enough, and only pulsed current wigglers, with little or no iron, are a possible solution.

The magnetic field is produced by a set of transverse bars, but an important contribution comes from the connecting longitudinal conductors and the return current bars. They produce large focussing or defocussing effects and the arrangement of the conductors is rather critical in order to get an acceptable focussing action in both X and Y directions.

Once this is established, the start up condition requires a very uniform wiggler, when the large signal condition requires a strongly tapered wiggler and this tapering must vary in proportion to the lasing power density. Since it is not possible to modify the period in a fraction of a microsecond, the only possible action is on the magnetic field intensity, governed by the drive currents. A solution, which could satisfy simultaneously all these requirements, seems possible between small signal and large signal operation and will be illustrated with the use of a simple code.

* H. LEBOUTET: "Pulsed undulators for high-efficiency FEL oscillators usable in the visible spectrum", PAC-91, San Francisco, p. 2763.

FABRICATION OF HIGH-FIELD SHORT-PERIOD PERMANENT MAGNET WIGGLERS*

R.W. Warren and C.M. Fortgang
Mail Stop H825
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

A permanent magnet wiggler is described that has been designed to lase at unusually short wavelengths. Its novel features include the following: all magnets are magnetized parallel to the wiggler's axis; only two pairs per period are used; the gap occupied by the electron beam is very small; the magnet arrangement is optimized for lasing on the third harmonic; the assembly of the magnets is carried out during continuous measurements of the field integrals; field gradients are measured with equal care; and residual errors are corrected by gluing small correcting magnets to appropriate places. The assembly, testing, and trimming of this wiggler was accomplished in less than a week. The wiggler has been used to lase successfully at 0.375 μm wavelength.

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Performance Characteristics of a Solenoid-Derived Wiggler

Y.C. Huang*, H.C. Wang+, J. Feinstein*, R.H. Pantell*

*McCullough 310
Electrical Engineering Department
Stanford University
Stanford CA 94305, USA

+China Academy of Engineering Physics
P.O. Box 523-50
Chengdu, Sichuan 610003, China

We have measured the magnetic properties of a wiggler derived from a staggered array of permeable pieces placed in the field of a solenoid. The wiggler was fabricated using slices from a bar of vanadium permendur, with each slice separated from its neighbor by an aluminum spacer. Without prior selection of magnetic pieces to ensure wiggler field uniformity, the measured field variation using the pulsed-current technique was ≈ 1.0%, with much of this attributable to the uncertainty associated with the sampling characteristic of the A/D interface.

The wiggler is 1.0 m long with a 2mm gap and 1cm period, and for a 7.0kG solenoid field the peak wiggler field was measured to be 10.8kG. This type of wiggler has a number of desirable features:

- It is relatively insensitive to fabrication errors.
- The wiggler field can be readily altered on a subsecond time scale by changing the current in a solenoid.
- There is a longitudinal component of magnetic field to confine the electron beam in the transverse plane.
- High wiggler fields can be obtained with a short wiggler period.

A comparison with computer simulations elucidates the dependence of the wiggler field upon the physical dimensions of the structure, on the saturation properties of the permeable pieces, and on the solenoid current. The trajectories of electrons through the wiggler have been calculated, and there has been an evaluation of the performance to be expected from a far infrared oscillator using this wiggler.

Tu3–01

24Tue

RECIRCULATION SCHEME IN THE SECOND PHASE OF THE JAERI FEL PROJECT

M. TAKAO, M. SUGIMOTO, M. SAWAMURA, R. NAGAI, R. KATO, E. MINEHARA, M. OHKUBO AND Y. SUZUKI

Free Electron Laser Laboratory, Department of Physics
Japan Atomic Energy Research Institute (JAERI)
Tokai, Ibaraki 319-11, Japan
Phone:+81-292-82-5462; Fax:+81-292-82-5939

At JAERI the free electron laser facility driven by the superconducting linear accelerator has been constructed to establish the necessary technology for the high power laser. As a first phase of the project, we plan to operate the FEL facility at a wavelength in the far infrared region ($\sim 40\ \mu$m) in a pulse mode. The repetition rate of the electron macro pulse is 10 pps and the pulse duration is 1 ms. One of the essential developments in the second phase project is to gain a high average output laser power, which is achieved by the constant wave operation of the FEL. Another important development is to make the laser wave length short. For the purpose of efficiently shortening the wave length of high power laser, we design the accelerator to recirculate electron beam. In recirculating, the electrons with some energy levels pass through the linac. Hence we investigate the multi-energy beam dynamics and the transport.

DESIGN OF A BEAM CONDITIONING SYSTEM FOR UT-FEL

R.Hajima, T.Muto and H.Ohashi
Department of Quantum Engineering and Systems Science, University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo 113 Japan
Telephone: +81-3-3812-2111 ex.6991. Telefax: +81-3-3818-3455

Abstract

A radio-frequency beam conditioning system, which consists of quadrupole magnets and an RF cavity excited at the TM210 mode [1], has been designed for the UT-FEL experimental parameters [2].

The geometry of the system and the cavity power was optimized for the small signal gain.

We found that the small signal gain increases in several times by the beam conditioning system.

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[2] R.Hajima et al., Proc. of the 14th FEL Conf., to be published.

Tu3–05

24Tue

DEVELOPMENT OF A 10MEV MICROTRON

Katsuhiro Kuroda, Katsuya Sugiyama and Atsuko Takafuji
Central Research Laboratory, Hitachi Ltd.,
1-280 Higasikoigakubo Kokubunji, Tokyo 185, Japan
Keiji Koyanagi and Ichirou Miura
Research & Development Center, Hitachi Medical Corp.,
2-1 Shintoyofuta Kashiwa, Chiba 277, Japan

Free Electron Lasers (FELs) require an accelerator with high beam current, low beam emittance, low beam energy spread and so on. We have developed a Russian-type microtron which can extract a 10MeV energy beam.

The acceleration principle of our microtron is as follows. Electrons emitted from a cathode, which is set on the outside wall of a cavity, are injected into the cavity. They are accelerated to about 0.5MeV by an electric field in the cavity and are simultaneously curved by an uniform magnetic field. The electrons (the 0th orbit) ejected from the cavity are curved by the magnetic field and injected into the cavity again. The electrons are further accelerated by about 1MeV while penetrating through the cavity. They travel along a circular orbit (the first orbit) and again go into the cavity where they gain energy by 1MeV. These actions are repeated until the energy reaches 10MeV. The radius Rn of the orbit is given by $Rn = \lambda (n+1)/2\pi$ for the nth ($n \geqq 1$) orbit, where λ is the microwave wavelength. The electron beam with a specified energy can easily be extracted by choosing the desired orbit number.

In the system, the beam current emitted from the LaB6 cathode is about 2A and the beam is accelerated by 3GHz microwaves of 2MW. The electron beam is pulsed with a $4\mu s$ macropulse length and a repetition rate of 1/1000 ~ 1/5000. The applied uniform magnetic field for revolution is about 0.2T. The measured average beam current and beam size are about 65mA and smaller than ϕ 5mm at 10MeV, respectively. The details of the design and the beam characteristics as determined by computer simulation and direct measurment will be shown in the meeting.

RF POWER TESTS FOR JAERI FEL SUPERCONDUCTING ACCELERATOR MODULES

M.Sawamura, M.Ohkubo, E.J.Minehara, R.Nagai, M.Takao,
M.Sugimoto, R.Kato, N.Kikuzawa†, and Y.Suzuki

Free Electron Laser Laboratory
Japan Atomic Energy Research Institute (JAERI)
Tokai-mura, Ibaraki-ken 319-11, Japan

†Department of Nuclear Engineering, Kyushu University
Higashi-ku, Fukuoka-shi, Fukuoka-ken 812, Japan

Four modules of superconducting accelerator for JAERI FEL linac have been installed. Low power rf tests in a continuous wave mode have been carried out at small rf coupling between a main coupler and a cavity. Each module shows more than $\sim 2 \times 10^9$ Q-value at 5MV/m accelerating field.

These modules are going to be operated in a pulse mode of $1 \sim 2$ msec macro pulse and 10 Hz repetition rate. High power rf tests in the pulse mode have begun at large coupling with 4 kW and 50 kW all-solid-state amplifiers and the rf control system.

The results of rf test will be reported in detail in the conference.

Tu3–09

PHOTOLITHOGRAPHIC IMAGING EXPERIMENTS USING AN ULTRAVIOLET FREE-ELECTRON LASER*

Brian E. Newnam, James W. Early, Donald A. Byrd, V. K. Viswanathan,
Steven C. Bender, Donald W. Feldman, Clifford M. Fortgang, John C. Goldstein,
Patrick G. O'Shea, Richard L. Sheffield, Roger W. Warren, and Thomas J. Zaugg
Los Alamos National Laboratory
Mail Stop J564
Los Alamos, New Mexico 87545 USA

24Tue

Ultraviolet radiation produced by a free-electron laser (FEL) has been used, for the first time, to record lithographic patterns in a photoresist-coated silicon wafer. These experiments were performed with the Los Alamos APEX FEL oscillator operating at 375 nm which is near the mercury-arc lamp I-line (365 nm) emission used in commercial lithographic production of 16-MBit integrated circuits. Using a Los Alamos reflective lithographic camera (9.4 X reduction factor, 0.3 numerical aperture), the resolution of the recorded images produced by FEL irradiation was <0.8 μm, close to the expected value. The limited number of tests with the FEL at 375 nm was supplemented by numerous lithographic experiments with the FEL photoinjector drive laser frequency tripled and quadrupled to 351 nm and 263 nm, respectively.

These experiments were motivated by the potential application of FELs to projection lithography for commercial production of gigabit integrated circuits if they can be extended to extreme-ultraviolet (XUV) wavelengths below 100 nm.[1] In advance of FEL operation in the XUV, however, we hoped to resolve several issues at longer wavelengths in the ultraviolet including: 1) photoresist response to trains of picosecond pulses with peak intensities ≥1 GW/cm^2, 2) benefits of adjustable temporal FEL coherence by lasing with synchrotron sidebands, 3) control of spatial coherence to avoid fringe formation in the aerial images, and 4) potential shot-to-shot beam jitter smearing of lithographic images. Our experimental results indicated that issues 1 and 4 should not limit applicability of an FEL. Issues 2 and 3 could not be addressed because the optical intensity within the FEL resonator was not high enough to achieve the predicted 1% spectral bandwidth via sidebands.

Silicon wafers coated with well-characterized photoresists (Dynachem 1024 and Shipley SNR 248) were provided by our industrial collaborators at Motorola Corporation and Texas Instruments, Inc. Transmissive test-pattern reticles were supplied by Dupont Photomask, Inc., and Texas Instruments, Inc.

1. B. E. Newnam, "Extreme Ultraviolet Free-Electron Laser-Based Projection Lithography Systems," Opt. Eng. 30, 1100-1108 (1991).

* Work supported by the Defense Programs Office of the U.S. Department of Energy.

Application of a Millimetre-Wave Free-Electron Laser to study Detection Processes

A Doria, G P Gallerano, E Giovenale, M F Kimmitt* and G Messina

Dipartimento Sviluppo Tecnologie di Punta, Ente per le Nuove Tecnologie l'Energia e l'Ambiente (ENEA), P O Box 65-00044 Frascati, Italy

The compact waveguide free-electron laser at ENEA is a very convenient and reliable source of short millimetre wave radiation [1]. At present it provides peak power up to 1kW in 4μs long pulses at wavelengths between 2.1 and 2.6mm but a new undulator is under construction to extend its range down to 500μm. As a first application of this new source we report its use in studying the response time, linearity and other parameters of several detectors, including:-

1) n-InSb electron bolometer at 77K. High purity n-InSb operating at 4K is a widely-used detector for the wavelength range 200μm-10mm. However, it is comparatively slow, with a response time of ~0.5μs. At higher temperature there is a severe loss in sensitivity but the mechanism becomes much faster. Our first results at 77K have shown a response time of a few nanoseconds but this is limited by the RC time constant as the present detector has a resistance of 2kΩ. There is also an unexplained second detection process, giving a small response with an opposite sign to the electron bolometer effect. We are now investigating this effect and designing a 50Ω detector to find the ultimate speed at 77K.

2) Photon drag. n-Ge photon drag devices will detect powers >10W with subnanosecond response at far-infrared wavelengths. For the first time we have observed a photon drag signal at millimetre wavelength, but the high absorption of germanium in this region prevents the design of optimum detectors. Other semiconductors have a more appropriate absorption at millimetre wavelengths and a silicon detector will shortly be tested. Photon drag detectors used at long wavelengths are particularly useful, as their voltage responsivity can be accurately predicted and they retain linearity to above 1MW power levels.

3) Ge:Ga. The longest wavelength detectable by extrinsic photoconductivity is about 180μm. However, we and other researchers have found significant response at millimetre wavelengths. Initially this was thought to be due to A^+ centres (holes very weakly bound to neutral acceptors) but we now suggest this is an electron bolometer process akin to n-InSb. We are attempting to confirm this by using detectors with different gallium dopings.

[1] F Ciocci, R Bartolini, G P Gallerano, E Giovenale, M F Kimmitt, G Messina and A Renieri. Phys Rev Letters 70, 928-931 (1993)

*Permanent address: University of Essex, Colchester CO4 3SQ, England

A POWERFUL AND EFFICIENT MULTIBEAM MICROWAVE FEL

L.Boscolo, G. Jianming, P. Radaelli, University and INFN of Milan, Italy
V.Variale, University and INFN of Bari, Italy

The paper presents the conceptual design and calculations of a 400 MW - 20 GHz multibeam FEL amplifier with a pulse length of 50 ns and a repetition rate of 1 kHz. That power level requires an electron beam of 600 MW since the calculated FEL efficiency results in 70%. The multi-outputs are obtained separating a 200 ns long electron beam into sections of 50 ns length. This can be done because the electron beam energy has a stepwise fashion, hence a dispersive system is able to disperd spatially the different sections. The electron beam of that length requires the electrostatic technology. We propose a Cockcroft-Walton of new design operating in pulsed mode. The relatively low values of the repetion rate and voltage (around 5 MV), even if the typical peak current has to be in the one hundred range, indicates that an electrostatic generator used as current compressor is a viable solution. The space charge effect is treated with care and it is shown that waveguide conducting walls are essential for reducing the effect at such extent that the FEL can operate in the Compton regime. The system is thought as a source of a high gradient LINAC, 100 MV/m, of the TeV Collider.

THE UV STORAGE RING FREE ELECTRON LASER FOR TIME RESOLVED FLUORESCENCE

M.E. Couprie[1), A. Delboulbé, D. Garzella, T. Hara[2) M. Billardon[3)

1) CEA DSM DRECAM SPAM, Cen-Saclay 91191 Gif Sur Yvette ;
2) University of Tokyo, Depart. of Nuclear Engineering
Bunkyo-ku, Tokyo, Japan
3) ESPCI, 10 rue Vauquelin, 75231 Paris Cedex 05

LURE Bât. 209 D Université de Paris-Sud 91 405 Orsay cedex
FRANCE

The performances of the Super-ACO storage ring free electron laser at 800 MeV have been recently improved : extension of the spectral range to the ultraviolet, enhancement of the laser output power, laser duration of 10 hours for the same injection of positrons in the storage ring, a good laser stability, a laser micropulse of 40 ps RMS...). Consequently, it was decided not only to develop the laser quality but to try also a first experiment using a UV storage ring FEL. A time-resolved fluorescence experiment in biology by the photon counting method was chosen, in order to take mainly advantage of the temporal structure of the FEL. It has been possible to perform a high quality measurement on NADH (a enzymatic cofactor) comparable to those required for the study of the proteins in solution. The interactive work between the users and the FEL group led to clarify the stability requirements. The improvement of the laser stability led us to develop a longitudinal feedback on the laser, still under test. Perspectives concerning the Super-ACO FEL facility will be given.

Tu3–17

24Tue

Temporal Structure Behaviour and Longitudinal Instabilities on the Super ACO Free Electron Laser

D. Garzella [a,b], M. E. Couprie [a,b], A. Delboulbé [a], T. Hara [a], M. Billardon [a,c].

(a) Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, CNRS/CEA/MESR
Bât 209D Université de Paris Sud, Centre Scientifique d'Orsay, 91405 ORSAY (FRANCE)

(b) : CEA/ DSM/ DRECAM/ SPAM. CEN Saclay, 91191 Gif sur Yvette, FRANCE.

(c) : ESPCI, 10 Rue Vauquelin, 75231 cedex 05 Paris, FRANCE

ABSTRACT

In an FEL the amplification of a stored light pulse varies according to different conditions of gain. This implies, for an SRFEL, a particular behaviour of the temporal structure. Measurements of the temporal width of the laser pulse versus stored ring current and versus the so called "detuning" have been performed with a dissector. The results here presented show how the temporal width is influenced by the evolution of the gain. The position of the laser pulse with respect to the center of positron bunch in equilibrium condition have been also measured. These results seem to confirmate, along with the existence of longitudinal instabilities of the laser pulse for a perfect synchronisation, the important role played by detuning in SRFEL saturation process. A system of longitudinal feedback on the optical cavity is currently under study, which could permit to have a more stable laser.

Observations of Frequency, Phase and Saturation Characteristics of a Raman, Free-Electron Laser Amplifier*

G. Bekefi

Department of Physics,
Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, MA 02139

We report observations of frequency phase and saturation characteristics of a free electron laser amplifier[1] operating in the Raman regime. The FEL is driven by a mildly relativistic electron beam (750 kV, 300 A, 25 ns) subjected to a combined axial magnetic field (2-12 kG) and a helical wiggler field (300 - 1600 G; 3.18 cm periodicity). The input into the FEL amplifier is provided by a high power magnetron (~50 kW) tuned to a frequency of 33.39 GHz. It is found that in the Group I regime of FEL operation the output frequency is upshifted by ~100 MHz, but smaller upshifts are observed in the group II or the reversed field[1] configurations. Phase shift measurements and further saturation studies in all three regimes will be also reported.

*This work was supported by AFOSR, NSF, and DOE.

[1]M.W. Conde and G. Bekefi, *Phys. Rev. Letters*, **67**, 3082 (1991); also IEEE Trans. Plasma Science, **20**, 240 (1992).

Tu3–21

24Tue

THE LOSSES MEASUREMENT FOR OPTICAL CAVITY

WITH FABRY-PEROT ETALON

I.V. Pinayev, V.M. Popik, T.V. Shaftan,

A.S. Sokolov, N.A. Vinokurov

Budker Institute of Nuclear Physics

11 Lavrentyev Ave., Novosibirsk, 630090, Russia

Tel: 7-(3832)-359977 Fax: 7-(3832)-352163

E-mail: pinayev@inp.nsk.su

Abstract

An intracavity glass plate with parallel planes changes dramatically light decay in optical cavity. This is due to fine structure of losses in the optical cavity depending on the wavelength. It was shown theoretically and experimentally that in this case the light intensity decay has with high accuracy the following dependence on time

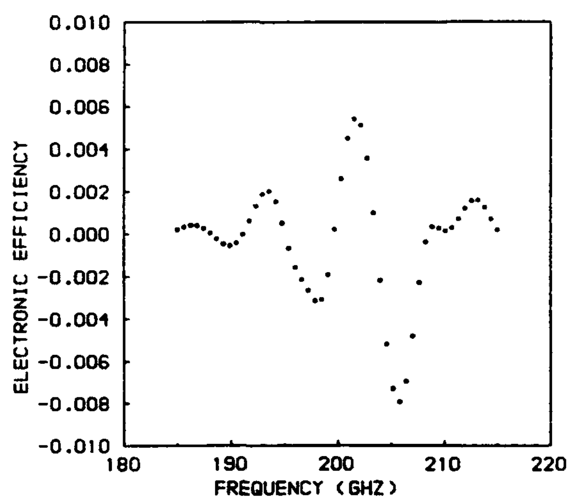
$$I(t) = I_0 \mathrm{erfc}(\sqrt{pt/T}),$$

where p - real losses of optical cavity per pass, T - period of roundtrip.

MICROUNDULATOR OPERATION, RESONANTLY ENHANCED BY A STRONG MAGNETIC GUIDE FIELD

G. Spindler and G. Renz
German Aerospace Research Establishment (DLR)
Institut für Technische Physik
Pfaffenwaldring 38-40
70503 Stuttgart, Germany

Small signal simulations show that a weak microundulator ($B_w \approx 50$ G, $\lambda_w \approx 5$ mm, 50 periods), operating in *magnetoresonance* with a strong guide field ($B_0 \approx 2.8$ Tesla), is able to produce an electronic efficiency, $\Delta\gamma/(\gamma - 1)$, of nearly one percent. The energy of the electron beam is 300 keV to yield a radiation frequency of 200 GHz. Theoretical considerations indicate that the spectral width of the spontaneous emission scales as $(B_w/B_0)^{2/3}$ at magnetoresonance, thus lending support to our surprising results in case of a weak microundulator. The paper finishes with a discussion about the technical verification of this novel FEL / GYROTRON scheme.



Small signal efficiency of a microundulator in magnetoresonance with a strong guide field.

24Tue

Tu3–25

GENERATION OF FEMTOSECOND X-RAYS BY 90° THOMSON SCATTERING*

K.-J. Kim, S. Chattopadhay and C.V. Shank

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720, USA

ABSTRACT

We propose Thomson scattering of short pulse laser beams by low energy electron beams at a right angle for generation of femtosecond x-rays. The basic idea is the observation that a low emittance electron beam can be focussed much more tightly in a transverse dimension than in the longitudinal dimension. Therefore much shorter pulses of x-rays can be generated (in the direction of the electron beam) by arranging the laser beam to meet the electron beam at a right angle rather than head on as in the Thomson backscattering configuration. Simple analysis of the process is presented by noting the similarity between the Thomson scattered radiation and the well-understood undulator radiation. Using the parameters of the recently developed femtosecond visible lasers and the high brightness electron guns, it is shown that 1 Å x-ray pulses, of 300 femtosecond duration, containing several 10^5 photons within 10% bandwidth per collision, can be generated.

* This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Temporally and Spatially Variable Grating for Generation of Submillimeter and Far-Infrared Waves*

Cha-Mei Tang

Plasma Physics Division
Naval Research Laboratory
Washington, DC 20375-5346

ABSTRACT

A wideband tunable radiation source that operates in the submillimeter and far-infrared regions of the spectrum is proposed. This concept is similar to a Smith-Purcell radiation. However, it does not require a conventional grating structure. An equivalent grating structure is produced by highly conducting strips on a normally non-conducting flat surface. Strips of the surface can be made highly conducting to resemble the top of a square grating. This concept is unique, because we proposed to change the grating spatially and temporally and proposed methods to accomplish this task. In this paper we will present radiation calculations for this kind of structure.

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24Tue

Tu3–29

FREE ELECTRON LASERS WITH TWO-DIMENSIONAL BRAGG RESONATORS

N.S.Ginzburg, N.Yu.Peskov, A.S.Sergeev
Institute of Applied Physics, Russian Academy of Science,
46 Uljanov Str., 603600 N.Novgorod, Russia

In order to realize spatial coherent radiation of ribbon relativistic electron beams with transverse dimension essentially exceeding the wavelength it was proposed in [1] to use a two-dimensional distributed feedback. This feedback can be provided in the Bragg resonator formed by two double-periodic corrugated metal plates, when additional transverse electromagnetic energy fluxes that synchronize the radiation of individual parts of the electron beam appear.

Analysis of the 2-D Bragg resonator shows that it has the spectrum of high-Q-factor modes. It is important that the mode with the highest quality has the spatial structure of a synchronous wave which does not depend on the transverse coordinate. So different parts of the electron beam have equal energy exchange with electromagnetic field. Computer simulation of excitation of the considered resonator by a ribbon electron beam confirms that one-mode space-coherent radiation can be realized up to transverse size 10^2- 10^3 wavelength.

The project of the FEL with the 2-D Bragg resonator driven by the ribbon relativistic microsecond electron beam with transverse size up to 10^2 cm, the power equal to tens of gigawatts, energy storage 10^2- 10^3 kJ [2] on the basis of accelerator U2 (INP RAS Novosibirsk) is considered. The radiation wavelength is 4 mm and output power can reach 10 GW.

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THE PERFORMANCE OF THE OK-4 OPTICAL KLYSTRON INSTALLED ON THE DUKE STORAGE RING

V.N.Litvinenko, J.M.J. Madey
FEL Laboratory, Box 90319, Duke University ,Durham, NC 27708-0319, USA
Telephone: (919)-660-2658; Fax: (919)-660-2671, e-mail: vl@phy.duke.edu

N.A.Vinokurov
Institute for Nuclear Physics, Novosibirsk, 630090, Russia

24Tue

Abstract

A 1 GeV electron storage ring dedicated for UV-VUV FEL operation is under construction at the Free Electron Laser Laboratory (Duke University, Durham, NC). Commissioning of the ring is scheduled to begin in 1994.

The OK-4 optical klystron, the first and still the only operational UV FEL, has been employed for a number of recent FEL experiments at the VEPP-3 storage ring bypass (Institute for Nuclear Physics, Novosibirsk, Russia). This program will be finished in 1993.

A new UV-VUV FEL project, based on collaborations between the Duke FEL Laboratory and the Institute for Nuclear Physics is described. The magnetic and optical systems of OK-4 optical klystron will be moved to Duke for the first FEL experiments using the DFELL storage ring. The main parameters of the DFELL storage ring, of the OK-4 optical klystron, and the experimental set-up are described.

The expected performance of the OK-4 driven by the Duke storage ring in UV, XUV and soft X-ray regions is presented. The OK-4 gain, lasing power in CW and Giant Pulse modes as well as spectral and temporal characteristics of the OK-4 FEL are given.

RADIATION COMPLEX ON THE BASE OF RACETRACK MICROTRON

K.A.Belovintsev, A.I.Bukin, E.B.Gaskevich, A.I.Karev, A.V.Koltsov, V.A.Kuznetsov, V.G.Kurakin, S.V.Sidorov

Department of High Energy Physics, Lebedev Physical Institute Leninsky Prospect 53, 117924 Moscow, Russia

24Tue

Assembling of the first stage of the radiation complex on the base of the Lebedev Physical Institute High Current Racetrack Microtron has been completed and the work of putting it into operation has been started.

The whole facility will include racetrack being under operation since 1986 [1] and several free electron lasers (FEL) to cover the wave range from millimeters to infrared (10 μm) region. Electron beams from different racetrack orbits (6 - 30 MeV) will be used to drive these lasers, the first stage corresponding to far infrared FEL (FIRFEL) excited by high intensity electron beam (10 - 20 A of peak current) directly from racetrack linac. Such strategy had been chosen to start FEL physics as well as light application program at early stage of the whole project realization allows at the same time to continue the work on racetrack improvement aiming the increase of its energy and intensity, that is of great importance for the next stages. The FIRFEL consists of short pulsed helical undulator with light gain of approximately 20 percent per path at 100 μm and open resonator of 1.65 m length. Original diagnostics and tuning system as well as computer control allow to stabilize the main laser parameters and provide fast automatical measurements during one accelerator pulse. The main features of the whole project and existing facility as well as light application program are discussed.

1. K.A.Belovintsev, A.I.Karev and V.G.Kurakin, Nucl. Instr. and Meth., A261 (1987), 36 - 38.

Status of the Liverpool microwave FEL

R.A. Stuart, J. Lucas, G. Dearden,
E.G. Quirk and A. Al-Shamma'a
Department of Electrical Engineering and Electronics
The University of Liverpool
P.O. Box 147, Liverpool, L69 3BX, UK

ABSTRACT

A free electron laser system developed at Liverpool has been successfully operated at 8.2GHz. The major feature of this experiment is that the electron beam has both an unusually low accelerating voltage and current (55kV and 1mA). The FEL interaction was made possible by combination of a short period wiggler magnet (λ_w = 1.9cm) and by using a waveguide klystron system. In this case the electrons were energy modulated at 8.2GHz by a klystron type buncher cavity before being accelerated into the wiggler interaction region. The results obtained will be presented.

Tu3–37

24Tue

Status of the KAERI Millimeter-Wave Free-Electron Laser[A]

Byung Cheol Lee, Sun Kook Kim, Sung Oh Cho*,
Young Uk Jeong, Byung Ho Choi, and Jong Min Lee

Atomic Spectroscopy Department, Korea Atomic Energy Research Institute, P. O. Box 7, Taedok Science Town, Taejon, 305-606, Korea

**Nuclear Engeering Department, Seoul National University, San 56-1, Shinrim-dong, Kwanak-ku, Seoul, Korea*

Progresses in the development of a millimeter-wave free-electron laser [1] driven by an electrostatic accelerator [2] are reported. The accelerator generates a 0.4-MeV, 2-A electron beam whose pulse width spans from 10 μs to CW. The first-stage of the experiment would be oscillation in pulse mode (10 μs) and, ultimately, the FEL would be operated in CW mode. The key issue in realizing CW operation is minimizing the loss of electron beam through its whole beamline. Details of the accelerator, undulator, cavity, together with the results of 1-D FEL simulations are presented.

References

[1] B. C. Lee, S. K. Kim, S. O. Cho, B. H. Choi and J. M. Lee "Design and construction of a high-power millimeter-wave free-electron laser' Proceedings of the Fourteenth International Free Electron Laser Conference, Kobe, Japan, August 23-28, 1992.

[A] **Work Supported by the Basic Research Program of ADD**

24Tue

EXACT AND VARIATIONAL CALCULATIONS OF EIGENMODES FOR THREE-DIMENSIONAL FEL INTERACTION IN THE EXPONENTIAL GAIN REGIME*

Ming Xie
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720, USA

ABSTRACT

We present an exact calculation of free-electron-laser (FEL) eigenmodes (fundamental as well as higher order modes) in the exponential-gain regime. These eigenmodes are solutions of the coupled Maxwell-Vlasov equations describing the FEL interaction, taking into account the effects due to the energy spread, the emittance and the betatron oscillations of the electron beam, and the diffraction and the guiding of the radiation field. The unperturbed electron distribution is assumed to be of Gaussian shape in four dimensional transverse phase space and also in the energy variable. The kernel of the integral equation for the eigenvalue problem in this case can be reduced to a one-dimensional integral, making it possible to solve for the eigenmodes numerically. A simpler analytical solution for the fundamental mode is also obtained by a variational technique, which is shown to agree well with the exact results. The approach in this paper permits an exact calculation of the exponential growth rate, transverse mode profile of the guided radiation mode, the electron distribution, the FEL gain spectrum, and the effect of the ellipticity of the electron beam cross section. It also permits a rigorous analysis of the evolution of transverse coherence of self-amplified spontaneous emission.

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Tu3–41

A PREBUNCHED MICROWAVE FREE ELECTRON LASER

24Tue

R. A. Stuart and G. Kong

DTI National Free Electron Laser Laboratory
Dept. of Electrical Engineering and Electronics
The University of Liverpool
Liverpool L69 3BX, England

ABSTRACT

A free electron laser system developed at Liverpool operates in the X-band of the microwave spectrum using a low current electron beam, which is prebunched by means of a microwave modulation before it is accelerated into a 55cm long interaction cavity. A theoretical model for this X-band interaction is established, taking into account of the effects of the waveguide and cavity coupling as well as possible higher mode interactions. The results obtained are compared with those obtained experimentally.

Electron Beam Focusing by Nonhomogeneous Electromagnetic Wave in Inverse FEL

Baryshevsky V.G., Dubovskaya I.Ya., Metelitsa O.N.

Institute for Nuclear Problems, Bobruiskaya 11, 220050, Minsk, Republic of Belarus

It is well known [1] that the interaction of an electron beam with an electromagnetic wave in a FEL leads to refraction of the electromagnetic wave by the beam. The refraction index resulted in this interaction can be written as [2]:

$$n = 1 + \frac{2\pi\rho_e}{k^2} f(0) \tag{1}$$

where ρ_e is the electron beam density, k is the photon wave vector and $f(0)$ is the elastic forward scattering amplitude. The index of electron refraction by an electromagnetic wave can be constructed in the same way. Since $f(0)$ is the forward scattering amplitude, this amplitude of electron scattering by a photon is proportional to the amplitude of photon scattering by an electron. Therefore the focusing (defocusing) of electromagnetic wave in a FEL means the existence of transverse forces focusing (defocusing) on electron beam. In the cylindrical coordinate system $\vec{e}_r$, $\vec{e}_\phi$, $\vec{e}_z$ the expression for the transverse force acting on the electron in helical wiggler FEL is:

$$F_s = \frac{mc^2}{2\gamma}\, a_w\, \frac{\partial a_s}{\partial r}\, (\cos\Psi\, \vec{e}_r + \sin\Psi\, \vec{e}_\phi) - \frac{mc^2}{2\gamma}\, a_s\, \frac{\partial a_s}{\partial r}\, \vec{e}_r \tag{2}$$

where a_w and a_s is the dimensionless wiggler field amplitude and the wave field amplitude, respectively, $\Psi = kz + \int k_w dz - \omega t$ is the slowly changing magnitude of the phases difference of the electron with regard to the field of a wiggler and an electromagnetic wave. In FELs we usually have $F_s \ll F_w$, where F_w is the ordinary wiggler field focusing force. However, in the inverse FEL, where $a_s \sim 1$, $F_s > F_w$. For example, at $\lambda_w \sim 3sm$ and electron and laser beams diameters $\sim 0.1sm$ $\quad F_s/F_w \sim 100\, a_s/a_w$.

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Tu3–45

24Tue

Tunability of a tapered FEL Amplifiers*

B. Levush, H. Freund** and T. M. Antonsen, Jr.
Laboratory for Plasma Research
University of Maryland, College Park

Free electron laser (FEL) amplifiers are tunable sources capable of producing high power, high frequency radiation needed in magnetic fusion applications. High efficiency can be achieved by varying the wiggler field strength and/or the wiggler period. In addition to the requirement of high efficiency, the FEL is required to be tunable for electron cyclotron heating applications in magnetic fusion devices. Although, the tunability of FEL's is well established, the tunability of a tapered FEL amplifier was not studied. In this paper we present an investigation of the tunability of a tapered wiggler FEL amplifier operating in the neighborhood of 94 GHz. The configuration of the FEL is one in which a sheet electron beam propagates through a rectangular wave guide in the presence of a planar wiggler field. The wiggler field is tapered in both period and amplitude. Substantial improvement in the efficiency over not tapered FEL is found. We also found that the tapered FEL amplifier is tunable over a reasonably wide range of frequencies by small adjustments in the energy and current of the electron beam.

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** Science Application International Corporation

24Tue

SPECTRAL WIDTH LIMITS IN "SINGLE MODE" FELs

S. Riyopoulos
Science Applications International Corporationl
1710 Goodridge Drive
McLean, VA 22102 USA
Tel: (703) 749-8933, Fax: (703) 821-1134

Sideband excitation near the carrier determines the minimum spectral width for steady-state FEL oscillators fed by continuous electron beams. A sideband separated by $\delta\omega$ from the carrier resonates with harmonics of the upshifted bounce frequency for trapped particles, $\delta\omega = n\ 2\gamma_z^2\ \Omega_b$. It is shown that the nonlinear shift of the carrier wavenumber from the vacuum value causes symmetric upper and lower sideband frequencies to decouple, accounting for the observed asymmetry in sideband spectra. Stability is determined by the electron distribution gradients, both across and around the ponderomotive equipotential surfaces[1]. We focus on sidebands excitated in the immediate vicinity of the carrier $\delta\omega \rightarrow 0$, in resonance with particles trapped near the separatrix $\Omega_b \rightarrow 0$. For electrons distributed uniformly around the equipotentials the growth tends to zero as $\delta\omega$, $\Omega_b \rightarrow 0$, despite the infinite number of contributing harmonics. However, the distributions produced by injected electron beams are nonuniform around the equipotentials, yielding finite growth rates Γ. Some sidebands are always unstable, setting a lower limit in the spectral width. In a cavity with reflection coefficient R and interaction length L the per pass gain is $G(\delta\omega) = R\ exp[\Gamma(\delta\omega)\ L] - 1$. It is proved that if the carrier is stable to amplitude perturbations $G(\delta\omega = 0) \leq 0$, then sidebands in the immediate vicinity are suppressed, $G(\delta\omega) < 0$ for $\delta\omega << 2\gamma_z^2\Omega_0$. This however does not apply to sidebands "far" from the carrier. If the oscillator is unstable the spectral width of the radiation scales as $\Delta\omega \sim min\{2\gamma_z^2\Omega_0,\ \omega/2\gamma_z^2 N\}$, N being the number of wiggler periods.

[1] S. Riyopoulos, Phys. Fluids **B3**, 2684 (1991).

FUNCTIONAL SCALING OF THE OPTICAL FIELD OF FREE-ELECTRON LASERS

S. Enguehard and B. Hatfield

Applied Mathematical Physics Research, Inc.
P.O. Box 383
Lexington, MA 02173
(617) 862-6357

ABSTRACT

The optical field emerging from an FEL is assumed to obey the paraxial equation where the index of refraction is generated from the electron beam. Non-ideal electron beam characteristics lead to fluctuations in the index of refraction and to aberations in the optical beam. The dynamical relationship between the structure functions (e.g. mutual coherence) of the outgoing optical beam and the global statistics of the electron beam perturbations is developed in the small-signal, small-gain regime. This relationship will be used to develop functional scaling of the optical beam quality with respect to changes in the characteristics of the electron beam. The use of the optical beam structure functions for electron beam diagnostics is discussed.

PULSE STACKING IN FELIX

B. Faatz

ENEA, Area INN, Dipartimento Sviluppo Technologie di Punta, CRE Frascati
P.O. Box 65 - 00044 Frascati, Rome, Italy

E.H. Haselhoff, V.I. Zhulin, P.W. van Amersfoort

FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie Euratom-FOM
Postbus 1207, 3430 BE Nieuwegein, Nederland

FELIX produces 20 μs-macropulses consisting of micropulses with a duration of the order of a few picoseconds separated by one nanosecond. For some possible applications, one short, high intensity pulse, typically several MW during a few picoseconds, is required. In order to achieve these specifications, several options are under investigation. One of these options, pulse-stacking, is investigated in this paper. It uses a separate cavity in which the individual micropulses created by the FEL are stacked on top of each other.

This preliminary study assumes an on-axis hole in the upstream mirror to couple the pulses into the cavity. The optimum geometry over the entire wavelength range from 10 up to 100 μm is covered. The size of the aperture, the radii of curvature of the mirrors, and the modestructure of the incoupled field is varied. It will be shown that the efficiency of stacking critically depends on the geometry of the resonator.

Tu3–53

24Tue

EFFICIENCY ENHANCEMENT OF A FEL WITH REVERSED GUIDE FIELD

A.A.Silivra, I.A.Goncharov,

Physical Faculty, Kiev University,
pr. Glushkova 6, Kiev, 252022, Ukraine

The equations of an energy exchange between a relativistic electron beam and a waveguide electromagnetic mode are formulated, and nonlinear stage of interaction of electromagnetic wave and beam is investigated. It is shown, in particular, that taking into account the betatron-like oscillations of electrons due to their nonadiabatic entrance into interaction region results in the insignificant efficiency change for the FEL with reversed guide field, while for the conventional FEL configuration this fact leads to efficiency decreasing. Moreover, configuration of a FEL with reversed guide field is characterized by broader frequency band (or is less sensitive for the detuning pparameter/energy spread in an electron beam) with regard to conventional configuration. The physical reasons and consequences of these facts are discussed.

MODIFIED THEORY OF SMITH-PURCELL RADIATION

N.K.Zhevago *and V.I.Glebov*

Russian Scientific Centre Kurchatov Institute

Moscow 123182, Russia

As is known, Smith-Purcell radiation (SPR) arises from electrons which move above a diffraction grating. All the existing theoretical approaches to this problem are based on the assumption that the grooves of the diffraction grating are not too deep to influence the boundary conditions. As a result, the radiation intensity appears to be independant either on the shape of the grooves and does not strongly depend either on the shape of the grooves or on the substance of the grating. On the other hand, it was noted in ref [1] that the diffraction grating with deep enough grooves may act similarly to the regular array of surface bumps. In other terms, fast electrons excite oscillations of substance electron density (plasmons), which may be strongly localized between the groves and are the instaneous source of SPR. In the present report we have developed the theory of SPR based on the excitation of local plasmons by relativistic electrons. Using this approach we have come to the conclusion that the radiation intensity may be substantially dependant on the shape of the grooves and on the dielectric constant of a grating. Using also some assumptions about the profile of a grating, we have calculated the radiation intensity for a certain number of metals and revealed that it may be several orders of magnitude greater than that predicted by the conventional theories. This may be of importance for using SPR for FEL.

[1] N.K.Zhevago Proceedings of FEL'92 Conference.

DYNAMICS OF ELECTRON BEAM IN ION UNDULATOR

Golub Yu.Ya., Rozanov N.E.

Moscow Radiotechnical Institute, Academy of Sciences

Varshavskoye shosse 132, Moscow, 113519, Russia

Abstract

A possibilities of ion beam using as an ion undulator for exiting of coherent electron beam oscillations in free electron lasers are investigated. A characteristics of electron beam oscillations are studied by means of formulated equations [1] describing a dynamics of high-current electron beam with an accounting for self-fields in axisymmetric ion channel, in general case, with longitudinal uniform magnetic field in paraxial steady-state (for electromagnetic fields) approximation. A simple formulae describing a dependencies of the amplitude and wave length of these oscillations on system parameters - ion/electron densities ratio, initial radii of electron and ion beams, energy of beams, magnitude of external magnetic field - are written. We have found the regimes in which the oscillations of electron beam (both annular and solid) are monochromatic and nondamping. A processes leading to the oscillation breakdown are studied.

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UNDULATOR SCHEME PROVIDING WIDE RANGE MAGNETIC FIELD TUNING

A.A.Varfolomeev, A.S.Khlebnikov, N.S.Osmanov
Coherent Radiation Laboratory, Russian Research Center
'Kurchatov Institute' Moscow 123182, Russia

Abstract

With the aim to find an undulator scheme providing operative K-strength variation in a wide range different schemes were investigated. The combination of a hybrid undulator and electromagnets was found to be most promisable. The best results were obtained with the scheme based on the redistribution of strong longitudinal magnetic field provided by additional permanent magnets arrays [1]. This scheme is more compact and ensure less heating in the central area near poles. The maximum variation range K= 0.5 - 2.2 was experimentally achieved with the 60 mm undulator period and with no variation of 12 mm gap. The maximum field amplitude was 3.9 kGauss. No water cooling was found to be needed.

Reference

[1] A.A.Varfolomeev, A.S.Khlebnikov, S.N.Ivanchenkov, N.S.Osmanov and A.H.Hairetdinov " Strong magnetic field microundulator with permanent magnets inserted into a solenoid ". Proceedings of the Fourteenth International Free Electron Laser Conference, Kobe, Japan, August 23-28, 1992. Nucl. Instr. and Meth. (1993).

TAPERED TWIN HELICAL UNDULATOR FOR LASING ON SELECTED HARMONIC

E.B.Gaskevich

Department of High Energy Physics, Lebedev Physical Institute Leninsky Prospect 53, 117924 Moscow, Russia

The way to select one harmonic frequency generation and to suppress others in free electron laser by using of a tapered twin helical undulator is suggested. Tapered twin helical undulator is the coaxial system of two different tapered helical undulators or microundulators (coils). The spiraling of the inner coil is opposite to that of outer one, periods of the coils being considerably different. One can construct FEL tuned to selected harmonic by appropriate choice of the law of tapering of each coil. For this harmonic the undulator looks like regular, while for others tapering takes place resulting to suppressing of these harmonics. The way for operative tuning to any particular harmonic is suggested. The one dimension Compton regime theory of a FEL with such undulator is developed.

Progress With the hybrid microwiggler

Qing-Xing Liu, Gui-Yong Wang, Suo-Zhu Yang,
Chuan-Ming Zhou, and Zhong-Xi Hui

Southwest Institute of Electron Engineering(SIEE)
P.O.Box 517, Chengdu, Ching 610003

A hybrid microwiggler FEL facility is currently under construction at SIEE. The poles of the hybrid microwiggler is less easy saturated than the poles of other iron-core microwiggler, so a hybrid micow-iggler can produce a wiggler field of high strength. For getting highr field, we have made some modific-ation. A prototype with a period of 10mm and a gap of 5 mm produce a peak field on axial in excess of 0.5T. The field of each half-period of the wiggler can be turned for improving field uniformity and electron beam matching at the wiggler entrance.

KEY WORDS Hyrid microwigger FEL

24Tue

Microwave Free Electron Laser Amplifier Experiments on SG-1 Device

Zhongxi Hui, Chuanming Zhou, Ruian Wu, Jianjun Deng, Yutao Chen,
Bonan Ding, Longzhou Tang, Jun Zhang, Fanbao Meng, Zuchong Tao
Chinese Academy of Engineering Physics
P.O. Box 523-65, Chengdu 610003, China
Zhenhua Yang, Shihong Tain, Zhiwei Dong, Shangqing Wu, Xiaojian Shu
Institute of Applied Physics and Computational Mathematics
P.O. Box 8009, Beijing 100088, China

Abstract

A high-gain microwave free electron laser amplifier experiments have been operated at CAEP by use of SG-1 device. A small signal output power of 50 KW in the super-radiation mode and 8 MW amplified microwave power have been measured. Present experiments on SG-1 device use a 2 KA, 3.4 MeV electron beam with a normalized emittance of 0.5 (πradcm) produced by induction linear accelerator. The 2m-long transport system forces the beam into the linearly polarized wiggler. The 4m-long electromagnetic wiggler is composed of specially shaped solenoids with 11 cm periods. The pulsed wiggler can provide a peak magnetic field on axis of 3 KG. Each two periods of the wiggler is energized by a separate power supply which allows variation of the strength and longitudinal profile of the wiggler magnetic field. Vertical and horizontal focusing of electron beam within the interaction regime is provided by the natural focusing of the parabolic pole face wiggler. The magnets surround a 3×10 cm^2 stainless-steel waveguide which serves as the interaction region. The microwave input to the amplifier is provided by a 34.6 GHz, 20 KW pulsed magnetron. This input signal is injected into the TE_{01} mode of the interaction region by means of waveguide tapers whose angle with the beam line is 30^0.

We have measured the signal of the amplified spontaneous emission (ASE). ASE output power is about 50 KW on the end of wiggler with the effective beam current 600 A. Nearly 20 db/m exponental gain, and 8 MW output power on the end of the wiggler with the input signal at about 300 W have been obtained. In order to study the dependence of FEL performance on the wiggler length, we have also measured the amplifier output power as a function of wiggler length. The signal does not reach saturation point within wiggler.

The experimental results of SG-1 device are compared with the simulation ones provided by IAPCM's 3D code WAGFEL.

Measurement of Actual Emittance of Relativistic Electron Beams

Liang FU Naiquan LIU Jianping DAI Xin CHEN
Physics Department, Tsinghua University
Beijing 100084, P.R.China

Abstract

A new, rapid and accurate instrument for beam diagnosis has been being studied at the Beijing Free Electron Laser(BFEL) Institute. An electron beam for FEL must have lower emittance, smaller energy spread and higher current. Thus, the beam diagnostic technique should be very good to meet these requirements. It is expected to measure the actual transverse emittance and the original phase diagram where the standard methods are not applicable. Our device consists of a scanning magnetic system, a tungsten slit and a fluorescent screen. The electron beam strikes the screen and produces light. By means of the CCD, the intensity distribution of the beam is recorded and transmited into the microcomputer so that the value of the emittance and the phase diagram can be acquired.

This paper describes briefly the principle of the device and introduces its construction. The measurement precision, the error of each part and the time used to get a phase diagram are also discussed.

Tu4-04

24Tue

DESIGN AND CONSTRUCTION OF INDUCTION LINAC FOR MM WAVE FREE ELECTRON LASER FOR FUSION RESEARCH

M.Shiho,S.Kawasaki[1], K.Sakamoto, H.Maeda, H.Ishizuka[2], Y.Watanabe[3], A.Tokuchi[4], Y.Yamashita[5] and S.Nakajima[6]
Japan Atomic Energy Research Institute, Naka Fusion Research Establishment, Naka-machi, Ibaraki-ken, Japan 311-01

The induction electron accelerator LAX-1 of JAERI is being upgraded to generate a higher mm wave FEL radiation for application to Tokamak plasma study. Typical features of the improvement are:

(1)Used are foils of new Fe-based Nanocrystallie soft magneticmaterial "Finemet" to form magnetic core of the acceleration unit. They have higher saturation flux density and lower power loss than the ones used before, and will permit higher repetition rate of the operation, up to the order 1kHz.

(2)The maximum beam energy and intensity will be increased to 2.5MeV and 3~5kA (1MeV and 3kA for LAX-1). The accelerating voltage V_a can be kept constant within +/-1% during the pulse, and moreover, the gradient of the voltage in time dV_a/dt can be controlled in the range of +/-20% to compensate the impedance change of the plasma diode, while the duration remains unchanged(~130nsec).

(3)The acceleration units are divided into two parts; one 1MV module is for the beam generation and operated with a constant driving voltage, and the other is for beam post acceleration. The latter is constructed so that the acceleration column may be separated from the driving circuit, and keep the acceleration gradient constant in it. We will have much more freedom with the device in the beam transport in the wiggler and the FEL operation.

We expect FEL radiation will be amplified to the level of multi-hundreds megawatts in the range of mm wave for 30~120GHz. It is planed that the radiation injected into JAERI middle size Tokamak, JFT-2M, to control the plasma through the electron cyclotron heating with the extremely high power microwave.

1. Saitama Univ. Facility of Sci. 255 Shimo-okubo, Urawa, Japan 388
2. Fukuoka Inst. of Tech. Wajiro, Higashi-ku, Fukuoka, Japan 811-02
3. Nissei Sangyo Co., 24-14,Nishi-shimbashi,1-chome,Minato-ku,Tokyo,Japan 105
4. NICHIKON Co. 2-3-1 Yagura, Kusatsu, Shiga, Japan 525
5. Kokubu Works, Hitachi Ltd.,Kokubucho 1, Hitachi-shi, Ibaraki, Japan 316
6. Magnetic & Electric Materials Research Lab, Hitachi Metals, LTD,Japan 360

Photoinjector for 6MeV S-band RF Linac at ILT/ILE Osaka University

M.Fujita, K.Imasaki, J.Chen, S.Kuruma, H.Furukawa, and C.Yamanaka
Institute for Laser Technology, 2-6 Yamada-oka, Suita, Osaka
M.Asakawa, N.Sakamoto, T.Yamamoto, N.Inoue, and S.Nakai
Institute of Laser Engineering, 2-6 Yamada-oka, Suita, Osaka
Y.Tsunawaki
Osaka Sangyo Univ., 3-1-1 Daito, Osaka
T.Agari, T.Asakuma, N.Ohigashi
Kansai Univ., 3-10-1 Senriyama-higashi, Suita Osaka

For an efficient free electron laser operation, an electron beam with low emittance, small energy spread, and high peak current is required. A photoinjector is one of the candidates to achieve such a high quality beam.

At ILT/IE, we are installing a photocathode rf gun to the 6MeV S-band rf linac system operated at 2856MHz. The driving laser is a frequency-tripled Nd:YAG laser with 20ps pulsewidth and 89.25MHz repetition rate. The cathode (LaB_6 or W) is heated up to 1000 degrees in order to improve the quantum efficiencies. It is expected to achieve the beam quality of $\Delta E/E \sim 1\%$ and $B_n \sim 10^{11} A/m^2 rad^2$. Using wigglers with $\lambda_w \sim$ 2cm and 7mm, 100 to 10 μm FIR radiation will be produced.

PARMELA and SUPERFISH codes are used to optimize photocathode operating conditions.

Tu4–08

24Tue

Developement of an Electrostatic Accelerator for a Millimeter-wave Free-Electron Laser[A]

Sung Oh Cho*, Byung Cheol Lee, Sun Kook Kim,
Young Uk Jeong, Byung Ho Choi, and Jong Min Lee

Atomic Spectroscopy Department, Korea Atomic Energy Research Institute, P. O. Box 7, Taedok Science Town, Taejon, 305-606, Korea

**Nuclear Engeering Department, Seoul National University, San 56-1, Shinrim-dong, Kwanak-ku, Seoul, Korea*

A 0.4-MeV, tandem-type, electrostatic accelerator has been developed as a driver of a CW millimeter-wave free-electron laser [1,2]. A grid-controlled thermionic electron gun generates 2-Ampere electron beam whose pulse width spans from 10 μs to CW. The most important issue in realizing CW operation of the FEL is minimizing beam loss through its beamline. Since the charging current is 15 mA and the beam current is 2 A, the current loss of the electron beam must be lower than 0.5 %. The accelerator has straight beamline from the e-gun to the collector, and have no external lenses. A multi-stage, depressed collector is used to capture the decelerated electron beam. Details of the accelerator and experimental results are presented.

References

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[2] B. C. Lee, S. K. Kim, S. O. Cho, Y. U. Jeong, B. H. Choi, and J. M. Lee, "Status of the KAERI Millimeter-wave Free-Electron Laser", Presented in this Conference.

[A] **Work Supported by the Basic Research Program of ADD**

EXCITE-PROBE FEL (CLIO) STUDY OF TWO-PHOTON-INDUCED CARRIER DYNAMICS IN NARROW GAP SEMICONDUCTORS

B.N. Murdin, R. Rangel-Rojo, C.R. Pidgeon, M.F. Kimmitt and A.K. Kar
Department of Physics, Heriot-Watt University

D.A. Jaroszynski
LURE, Universite de Paris Sud, Orsay

In a previous paper [1] preliminary measurements were reported of two-photon absorption in the narrow gap semiconductors InAs and InSb, measured for the first time over a broad spectral range - from the one-photon to two-photon threshold (E_G to $E_G/2$) - utilising the mid-infrared tunability of CLIO. At the time an assumption had to be made concerning the lifetime of the excited carriers in order to interpret the results with the time structure of the exciting FEL. We have now made a direct measurement of the lifetime of two-photon-induced free holes in InAs using an excite-probe technique. The lifetime was determined by measuring the transmission of an adjustable delayed weak picosecond probe pulse following an intense picosecond pump pulse from CLIO. Results show good agreement with the exponential behaviour expected, and lifetimes of between 2.5ns and 10ns were measured consistent with Auger scattering. Strong power limiting was observed at wavelengths between E_G and $E_G/2$, which yielded the two-photon absorption coefficient over the entire range by fitting a simple theoretical model. The results are consistent with a model for the two-photon transition probability incorporating the non parabolic band structure of narrow gap semiconductors.

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24Tue

INVERSE FREE ELECTRON LASER ACCELERATOR DEVELOPMENT*

A. Fisher, J. Gallardo†, A. van Steenbergen
National Synchrotron Light Source and Physics Department†
Brookhaven National Laboratory, Upton, NY 11973

J. Sandweiss
Physics Department, Yale University
New Haven, CT 06511

ABSTRACT

The study of the INVERSE FREE ELECTRON LASER, as a potential mode of electron acceleration, is being pursued at Brookhaven National Laboratory. Recent studies have focussed on the development of a low energy, high gradient, multi stage linear accelerator. The elementary ingredients for the IFEL interaction are the 50 MeV Linac e^- beam and the 10^{11} Watt CO_2 laser beam of BNL's Accelerator Test Facility (ATF), Center for Accelerator Physics (CAP) and a wiggler. The latter element is designed as a fast excitation unit making use of alternating stacks of Vanadium Permendur (VaP) ferromagnetic laminations, periodically interspersed with conductive, nonmagnetic laminations, which act as eddy current induced field reflectors. Wiggler parameters and field distribution data will be presented for a prototype wiggler in a constant period and in a $\approx$ 1.5%/cm tapered period configuration.

The CO_2 laser beam will be transported through the IFEL interaction region by means of a low loss rectangular or circular waveguide. Short waveguide test sections have been constructed and have been tested using a low power cw CO_2 laser. Preliminary results of guide attenuation and mode selectivity will be given, together with a discussion of the optical issues for the IFEL accelerator.

In addition, we have carried out 1-D and 3-D simulations of a single and multi module accelerator. Results of the numerical studies including wiggler errors will be presented.

*Work performed under the auspices of the U.S. Department of Energy, under Contract No. DE-AC02-76CH00016.

CLIC DRIVE BEAM GENERATION BY INDUCTION LINAC AND FEL PRELIMINARY EXPERIMENTAL STUDIES

J.GARDELLE, R.CORSINI *, J.GRENIER,
C.JOHNSON *, J.L.RULLIER

C.E.A./C.E.S.T.A., PO Box 2, 33114 LE BARP, (France)
*C.E.R.N, 1211 GENEVA 23, (Switzerland)

Generation of the intense 30 GHz drive beam for CLIC[1] (CERN Linear Collider) presents several interesting technological challenges. CERN has now actively engaged theoretical and limited experimental studies related to the application of linear induction accelerator and FEL to CLIC drive beam generation.

A test facility is running at CESTA with the initial aim to generate and measure the properties of a low-energy bunched beam. The LELIA induction accelerator[2] delivers a 1-2.5 MeV, 1 kA, 50 ns electron beam. Its transport through a wiggler is studied with a hybrid planar wiggler mock-up[3] (8 cm period, 8 periods, ≈ 1500 G). In an FEL amplifier configuration at 1.2 MeV, we expect to measure the electron beam spatial modulation at 35 GHz due to FEL effects. This beginning of bunching will be measured by using a high-speed streak camera (picosecond level), analysing Cerenkov emission of the electron beam at the wiggler exit. Because of space charge problems at 1.2 MeV, next step should be the use of a longer wiggler, working at 2.5 MeV, to observe a better bunching.

1- W.SCHNELL, Proc.LC92 ECFA Workshop on e+e- Linear Colliders, Garmissch-Paretenkirchen, SL/92-51, 1992
2- J.BARDY et al., NIM A 304, 1991 p 311
3- J.GRENIER, J.GARDELLE, this conference

Tu4–16

24Tue

GENERATION OF THE SECOND HARMONIC IN A FEL WITH AN AXISYMMETRIC UNDULATOR OF THE INDUCTION TYPE

V.D. Sazhin, N.I. Karbushev and P.V. Mironov
Moscow Radiotechnical Institute
Varshavskoye shosse, 132, 113519 Moscow Russia
fax (095)314-1053

It was shown experimentally that the generation of microwave radiation by a hollow kiloampere electron beam of microseconds duration in an axisymmetric undulator, consisted of alternating conducting and dielectric rings, and in an axial magnetic field of a solenoid occurs most effective, when the period of cyclotron gyration of electrons was equal to the undulator period or to half of that. The last case corresponds to resonance pumping of the second harmonic of the undulator motion of electrons and is equivalent to using of the undulator with a two times less period. At the second resonance a rather good propagation of the electron beam through a waveguide and the stable generation of microwave radiation were observed, while the first resonance led to strong settling of electrons on the waveguide wall, what prevented from increasing of microwave power. The maximum second harmonic generated power of microwave radiation reached several megawatts in cantimeter and millimeter ranges of wavelengths.

Generation of Intense Coherent Undulator Radiation using a High-current Relativistic Photoelectron Beam generated by an Ultra-short Excimer Laser Pulse

Young Uk Jeong[A], Yoshiyuki Kawamura*, Koichi Toyoda*, Chang Hee Nam, and Sang Soo Lee

Department of Physics, Korea Advanced Institute of Science and Technology, 373-1, Kusung-dong, Yusung-ku, Taejon, Korea

**Riken, The Institute of Physical and Chemical Research, Wako-shi, Saitama 351-01, Japan*

Intense coherent radiation has been produced by a short-pulse, high-current-density relativistic photoelectron beam passing through an undulator. The photoelectron beam is generated by an excimer laser pulse (0.5 ps, 248 nm, 1 GW/cm^2) incident on a Zn-cathode, and the maximum current density is 1 kA/cm^2. This value is more than 100 times higher than the space-charge-limited current density calculated by the Child-Langmuir's law, which phenomenon is expected when the bunch length of the electron beam is much shorter than the distance between cathode and anode [1]. Measured power of the coherent undulator radiation was 10^4-10^6 times stronger than that of theoretically calculated incoherent radiation. The pulse broadening of the electron beam during acceleraion was analyzed from the dependence of the coherent radiation power on the number of the electrons in a bunch [2].

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[2]. Y. U. Jeong, Y. Kawamura, K. Toyoda, C. H. Nam, and S. S. Lee, Phys. Rev. Lett. 68, 1140 (1992).

[A] Permanent Address : *Atomic Spectroscopy Department, Korea Atomic Energy Research Institute, P. O. Box 7, Taedok Science Town, Taejon, 305-606, Korea*

Tu4–20

24Tue

Bunch length measurement on CLIO

E. Glotin, J.-M. Berset, R. Chaput, D. Jaroszynski, J.-M. Ortéga, R. Prazérès.
LURE, Bât. 209 D, Centre Universitaire d'Orsay, 91405 ORSAY, FRANCE.

The length of both electron and laser micropulses has been measured under various conditions.

The width of the electron bunches varies between 8 and 12 ps FWHM for standard operation of the linac in our usual 32-50 MeV range. Measurement is performed by dephasing the electron beam with respect to the RF wave in the accelerating section, so as to induce a correlation between the phase and the energy of the electrons. Bunch shape can therefore be deduced from the induced energy spectrum. Good agreement has been obtained between experimental results and simulations with PARMELA, using different values of the RF power injected in the buncher.

Laser micropulses are measured using a 2^d order auto-correlation method, using a Michelson interferometer and a non-linear crystal. The measured pulse length varies between 2 and 11 ps at 8 μm, depending on the detuning of the optical cavity length. Shorter bunches of ps duration have been produced by running the linac in the "dephased" configuration described above and selecting a short slice in the energy-stretched electron bunch with a dipole magnet and an adjustable slit.

Possibility of optical pulse compression using a grating device and chirped pulses has been studied by simulations, and the experiment is in progress.

OBSERVATIONS OF THE SUPER-ACO FEL MICROPULSE WITH A STREAK CAMERA

T. Hara[a], M.E. Couprie[a,c], A. Delboulbé[a], P. Troussel[b], D. Gontier[b] and M. Billardon[a,d]

(a) Laboratoire pour l'Utilisation du Raymonnement Electromagnetique, Bât.209D, Université de Paris-Sud, 91405 Orsay, France
(b) CEA, Centre d'Etude de Limeil Valenton, 94195 Villeneuve St. Georges, France
(c) CEA/DSM/DRECAM/SPAM/CEN, Saclay, 91191 Gif-sur-Yvette, France
(d) ESPCI, 10 rue Vauquelin, 75231 Paris, France

Measurements on micropulses with a streak camera (Thomson TSN506) have been carried out in collaboration with CEA/DAM since last year at the Super-ACO storage ring Free Electron Laser.

The RMS width of the micropulse ($\sigma_{laser} \approx 26ps$) is measured and the temporal jitter of the laser micropulse is observed. Besides that, in some cases, a longitudinal distribution of the micropulse is different from a Gaussian. Such a deviation from a Gaussian has not been observed so far with the dissector, because the dissector is a stroboscopic pico-second detector, which averages over a large number of pulses.

Some measurements have been performed in the Q-switched mode; the laser micropulse seems to be more stable and with less jitter. It appears to be preferable for users.

Coherent Spontaneous Radiation and Superradiant Amplification of Ultra-Short Microwave Pulses from a Photocathode Linac FEL*

G. Le Sage, F.V. Hartemann, D.B. McDermott and N.C. Luhmann, Jr.
UCLA Electrical Engineering Department, Los Angeles, CA. 90024
P.G. Davis, S.C. Hartman, S. Park, R.S. Zhang and C. Pellegrini
UCLA Physics Department, Los Angeles, CA. 90024

The study of ultra-short, high-power, millimeter-wave and FIR pulses of coherent electromagnetic radiation has numerous applications ranging from surface and material physics to the next generation of ultra-wideband radars. A strong effort is currently underway at UCLA to develop high-brightness, ultra-short pulsed electron sources for coherent electromagnetic radiation generation. These new devices are based on high-gradient RF photocathode linacs.

The $1\frac{1}{2}$ cell RF gun operates at 2.856 GHz with a 20 MW SLAC klystron. The strong electric field built up within the half cell, near the photocathode, quickly accelerates the photo-electrons, thereby maintaining a very low beam emittance. The photocathode is driven by a frequency-quadrupled Nd:YAG laser with 1-10 ps FWHM and produces a bunch charge ranging from 10 pC to 1 nC. The beam energy obtained at the output of the $1\frac{1}{2}$ cell linac is in the 3-4 MeV range.

The electron bunch is subsequently transversally accelerated by a 2 m long, 8.5 cm-period, 3 kG, helically polarized wiggler to produce high-power coherent electromagnetic radiation in the Ka-band. Theoretical calculations show that in the coherent spontaneous radiation limit, where the bunch essentially behaves as an accelerated point charge, peak powers in excess of 10 MW can be achieved with RF pulse lengths ~ 1 ns. In the waveguide TE_{11} grazing limit, where superradiant high-gain Compton FEL amplification is obtained, the predicted power levels are even higher, in excess of 100 MW, with pulse widths ranging between 10 ps and 100 ps. Theoretical considerations and experimental progress will be reported.

* Work supported by DOE under Grant DE-FG0-90ER-40565, AFOSR under Grant F49620-92-J-0175 and Rome Laboratory (ATRI) under Contract F3062-91-C-0020.

HIGH GAIN FELS FOR THE DUKE STORAGE RING

B. Burnham, V. Litvinenko, J.M.J. Madey, Y. Wu

Duke University Free Electron Laser Laboratory

Box 90319 Duke University Durham, NC 27708-0319, USA

The Duke storage ring is under construction at the Free Electron Laboratory in Durham, North Carolina. One of the ring's 34 meter long straight sections is dedicated to high gain FEL research. A lattice for installation of a 27 meter FEL system is presented. Expected electron beam parameters for the ring are given. Results of computer simulations for a high gain phase displacement amplifier and distributed optical klystron in the soft X-ray region are described. A brief comparison with theoretical estimations is provided.

ON APPLICATION OF TIME-DEPENDENT UNDULATOR TAPERING TO INCREASE A FEL OSCILLATOR EFFICIENCY

E.L. Saldin[†], E.A. Schneidmiller [†] and M.V. Yurkov

Joint Institute for Nuclear Research,
P.O. Box 79, Head Post Office, Moscow 101000, Russian Federation
[†]*Automatic Systems Corporation,*
Smyshlyaevskoe Shosse 1a, Samara 443050, Russian Federation

24Tue

ABSTRACT

A novel concept of a high efficiency FEL oscillator is discussed. A method of efficiency increase consists in the usage of a multicomponent undulator with time-dependent undulator tapering. Feasibility of the proposed scheme is illustrated by results of n :merical simulations. It is shown that this scheme may be realized at present day level of accelerator and FEL technique R&D. Numerical example presented illustrates a possibility to construct high efficiency FEL oscillator with time-dependent undulator tapering using driving beam from superconducting accelerator operating in a continuous and quasi-continuous mode.

THE ULTRASHORT IMPULSES FORMATION IN A FEL WITH ELECTROMAGNETIC PUMP WAVE

A.A.Silivra, N.Ya.Kotsarenko, A.B.Draganov

Physical Faculty, Kiev University,
pr. Glushkova 6, Kiev, 252022, Ukraine

The nonlinear stage of interaction of electromagnetic waves and beam modes is investigated, and the possibility of ultrashort impulses of electromagnetic waves formation is shown. The analyses of this interaction is based on the analytical and numerical solution of reduced differential equations for the amplitudes of the interacting waves.

It is shown that under certain assumption from this system of equations one can obtain the well-known sin-Gordon equation which has the solution in so called π - impulse form. The asymptotic behavior of this solution shows that the impulse length Δz trends to decrease $\Delta z \propto t^{-1}$ while the impulse amplitude increases $\mathcal{E} \propto t$.

The numerical simulation of such interaction is fulfilled for the different possible boundary conditions. One of the most interesting cases is realized when the electron beam is not modulated and the signal wave has the impulse shape while the pump wave is homogeneous alongside the interaction region. For example, if the interaction length of FEL is 200 cm, the intensity of "pump" wave is 100 KW/cm^2 , and the initial intensity of "signal" wave is 200 KW/cm^2 , then amplitude growing of "signal" wave is 20 times and duration of output impulse is 0.3 nsec.

STATUS REPORT ON THE CEBAF IR FEL

G. R. Neil, S. V. Benson, J. J. Bisognano, Y. Chao, D. Douglas, H. F. Dylla, L. Harwood, C. W. Leemann, H. Liu, P. Liger, D. Machie, D. V. Neuffer, C. Rode, S. N. Simrock, C. K. Sinclair, J. VanZeijts, and B. Yunn
Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue, Newport News, VA 23606-1909 USA

The CEBAF 4 GeV recirculating, superconducting electron linac, is being commissioned as a high quality source for nuclear physics. The superconducting linac technology is also ideal as an FEL driver. The 45 MeV front end linac is in the process of being modified for the addition of a high-charge DC photocathode injector. A single cryounit operating at >10 MV/m has been fabricated for use with this gun to form high peak current pulses which can be used for our IR FEL. This beam is to be accelerated through two existing cryomodules to 50 MeV so that an FEL with a 6 cm period wiggler produces kilowatt output powers in the 4 to 20 micron range in the fundamental. Third harmonic operation may extend IR performance down to 1.5 microns. Status of the installation will be reported.

LINAC DRIVER FOR THE FEL PROJECT AT P.N.LEBEDEV INSTITUTE.

A.V.Agafonov, G.A.Gevorgyan, E.G.Krastelev,
A.Yu.Kustov, A.N.Lebedev, N.N.Martynchuk,
P.S.Mikhalev, V.A.Fedotov, S.M.Zakharov
and B.N.Yablokov

P.N.Lebedev Physical Institute,
Russian Academy of Sciences,
117924, Moscow, Leninsky prosp., 53, Russia.

The present status of the specialized RF linac for the IR FEL project at P.N.Lebedev Physical Institute designed for 20-25 MeV energy and up to 300 A peak current in a 100-200 μs long train of 100-200 ps pulses is described. The accelerator is based on the scheme of a number of independently fed cavities operating at 150 MHz frequency and RF photocathode electron gun with an UV laser driver with active mode synchronization. The initial part of the accelerator for 4 MeV has been constructed and now is under test. Results of previous experiments with low-current test beam and modelling of the high-current short-pulse beam behavior are presented.

ELECTRON-BEAM DIAGNOSTICS FOR THE AVERAGE POWER LASER EXPERIMENT / HIGH POWER OSCILLATOR (APLE / HPO) PROGRAM

M. Wilke, D. Gilpatrick and D. Barlow
Los Alamos National Laboratory, Los Alamos, NM 87545, USA

R. Greegor and D. Dowell
Boeing Defense and Space Group, Seattle, WA, USA

The average power laser experiment / high power oscillator (APLE / HPO) is a collaboration between Boeing Defense and Space Group and Los Alamos National Laboratory to build a free-electron laser (FEL) operating at a wavelength of 10μm with an optical output power of 10kW. The electron beam will have an energy of 18MeV with an average current of .23 A, so that at 25% duty factor the average power will be 1.0MW which will require the use of both low power e-beam diagnostics for tune-up and commissioning and high power e-beam diagnostics for full power running. Exclusively low power (<100W) diagnostics will be accomplished using intrusive screens (optical transition radiation, Cherenkov radiation and florescence from Cr/Al_2O_3). At both high and low power, screens with apertures, striplines, ferrite core current monitors and flying wires will be used. A special capacitive probe beam position monitor has been designed to fit into the elliptical (11.5mm x 23.0mm) beam tube of the oscillator wiggler. To protect the beam line hardware at high power, fast shutdown (<10μsec) of the drive laser has been incorporated by using photomultiplier tubes, ferrite core current monitors and a valid beam signal produced by the the stripline beam position electronics.

FEM Experiment with Prebunched Beam at TAU : Status Report

M. Arbel, D. Ben-Haim, M. Cohen, M. Draznin,
A. Eichenbaum, A. Gover, H. Kleinman, A. Kugel, Y. Pinhasi, Y. Yakover.

Dept. of Electrical Engineering - Physical Electronics
Faculty of Engineering, Tel-Aviv University,
Ramat-Aviv, 69978, Israel
FAX: 972-3-6429540, e-mail:moshec@eng.tau.ac.il

24Tue

Abstract

The status of an experimental project aimed to demonstrate FEM with prebunching in a depressed collector configuration is presented. The FEM utilizes a $1.5A$ prebunched electron beam obtained from a convergent Pierce-type gun which is part of a commercial traveling-wave-tube (TWT). The electron beam is bunched at $5.5GHz$, by the TWT section and then accelerated to $70KeV$. The bunched beam is injected into a planar wiggler ($B_w = 300G$, $\lambda_w = 4.4cm$) constructed in a Hallbach configuration with 17 periods and utilizes two long permanent magnets for horizontal focusing. We plan to study the FEM gain enhancement and radiation features due to the prebunched (superradiant) mode of operation. In an oscillator configuration the experimental set-up will enable study of seed injection by prebunching. Simulation of the FEL operation shows expected gain of approximately 10 and r.f. output power of $5KW$. In this presentation we review the design of the main parts of the experimental set-up, and present some analytical, numerical, and experimental results.

Tu4–40

24Tue

A Free-Electron Laser Model Without The Slowly Varying Envelope Approximation

Eltjo H. Haselhoff
FOM-Instituut voor Plasmafysica "Rijnhuizen"
Edisonbaan 14
3439 MN Nieuwegein
The Netherlands

A common assumption in the derivation of the FEL dynamical equations is a radiation pulse with an envelope that varies only slowly on the scale of a radiation wavelength. This 'Slowly Varying Envelope Approximation' (SVEA) simplifies the analysis, but is violated when phenomena like strong superradiance or synchrotron instabilities are modeled.
In this contribution an FEL model is presented in which no SVEA assumptions are made. It is shown how the mathematical form of this set of equations closely resembles the 'classical' SVEA FEL equations.

CONTROLLING THE RATE OF HARMONICS IN A FREE ELECTRON LASER

D. Iracane, D. Touati, P. Chaix.
C.E.A. PTN,
91680 Bruyères-le-Châtel, France

A Free Electron Laser (FEL) with a plane wiggler generates odd harmonics of the fundamental wavelength. In order to increase the rate of the third harmonic, we study the radiation emitted by a FEL in an oscillator configuration with a two-sections wiggler, the period of the first section being three times smaller than the period of the second one.

Using a multifrequency model, including the description of the harmonics of both the wiggler magnetic field and the laser wave, we point out separate regimes with sharp transitions that emphasize the complex coupling between the two sections. Depending on the length of the first section, numerical simulations exhibit the following behaviors :

- When this length is small, the fundamental wavelength largely dominates the third harmonic.
- As soon as the first section is long enough to generate significant radiation on the third harmonic, a second regime appears. It is characterized by the growth and saturation of the fundamental wavelength during the first passes, then followed by the growth and saturation of the third harmonic, while surprisingly the fundamental wavelength collapses.
- For longer sections, a third regime occurs : both wavelengths grow and saturate simultaneously. The saturation is an equilibrium which can be easily tuned since the rate of the third harmonic decreases continuously from 100 % to 0 % by increasing the length of the first section.

All these transitions can be interpreted in a relatively simple way, as resulting from the displacement of the electrons in the phase space, due to the first section, above or below the resonant energy associated to the second one.

Going further to investigate the general influence of the shape of the wiggler field onto the generation of the third harmonic, and more generally on the efficiency of the FEL, we provide a general formulation of the problem in terms of optimal control.

Tu4—44

24Tue

FREE ELECTRON GAIN SCALING FUNCTION INCLUDING ALTERNATING GRADIENT FOCUSING*

L.H. Yu, C.M. Hung+, D. Li, S. Krinsky
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, NY 11973

ABSTRACT

In the exponential regime before saturation, we present a variational calculation of the gain of a free electron laser (FEL), with alternating gradient focusing used to supplement the natural focusing of the wiggler. The longitudinal velocity modulation due to the quadrupole focusing is properly taken into account, and it is found that it does not prevent quadrupole focusing from efficiently increasing the gain. Our analytic calculation agrees with computer simulation to a few percent, and it provides rapid computation facilitating FEL design optimization.

+ Present address, Physics Department, SUNY at Stony Brook, Stony Brook, New York 11794

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SIMULATIONS OF PERFORMANCE OF THE FEM OSCILLATOR FOR FUSION AT 130-250 GHz

A.V.Tulupov, M.J. van der Wiel, W.H.Urbanus
FOM Institute for Plasmaphysics "Rijnhuizen", Association EUROATOM-FOM,
Postbus 1207, 3430 BE Nieuwegein, The Netherlands

M.Caplan
Lawrence Livermore National Laboratory, P.O.Box 808 L440
Livermore, CA 94550, USA

The performance of a 1 MW, long pulse, 130-250 GHz free-electron maser being designed in the FOM-Institute of Plasmaphysics for fusion applications has been simulated by a fully 3-D, AC and DC space charge included, non-wiggle averaged, particle-pusher code. In comparison with previous designs a new shorter construction of a step-tapered undulator providing suppression of the double frequency amplification on the linear stage and a perfect matching of the power grow on the nonlinear stage is considered. The dependencies of the linear gain and output power on the operating frequency, reflection coefficient, gap length between two undulator sections and electron beam focusing efficiency are examined. Particular attention has been devoted to the influence of space charge on the operation of the FEM oscillator. Longitudinal space charge reduces the linear gain but increases the level of power which can be reached inside the resonator. It has been shown that for the fixed undulator length there is an optimum value of the electron beam current density providing sufficiently high linear gain and output power.

ELECTRON BEAM CONDITIONING METHODS IN FREE-ELECTRONS LASERS*

Phillip Sprangle[a)], B. Hafizi[b)], G. Joyce[a)], and P. Serafim[c)]

The intrinsic energy spread and the emittance on an electron beam leads to a spread in the axial electron velocity. Since the free-electron laser interaction is sensitive to the axial velocity of the electrons, energy spread and emittance limit the operating wavelength, gain and efficiency of the device. We propose two methods for reducing the axial velocity spread in electron beams by redistributing the electron energy via interaction with an axially symmetric, slow, TM waveguide mode. In the first method, the energy redistribution is correlated with the electrons' betatron amplitude, while in the second method it is correlated with the electrons' synchrotron amplitude. Reductions of more than a factor of 40 in the rms axial velocity spread have been obtained in simulations.

a) Plasma Physics Division, Naval Research Laboratory, Washington, DC 20375, USA
b) Icarus Research, 7113 Exfair Road, Bethesda, MD 20814, USA
c) Northeastern University, Boston, MA 02115, USA

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24Tue

Electron Velocity Instability in Combined Helical Wiggler and Axial Guide Magnetic Fields

Xiaojian Shu
Institute of Applied Physics and Computational Mathematics, P.O.Box 8009, Beijing 100088, China

ABSTRACT

The single–particle orbits of relativistic electrons, in combined helical wiggler and axial guide magnetic fields, have been studied. Based on the numerical simulations of the Raman free–electron laser experiment in Shanghai Institute of Optics and Fine Mechanics, a new motion instability of off–axis electrons has been shown and analysed. This instability is found to occur in velocity space of electrons with a beat between Ω_1 and $2\Omega_2$ depending on the radial displacement of the electrons from axis, but without any large radial drifts in position space, which provides an explanation of an unexpected dip in radiation power that has been observed in the experiment.

Tu4–52

24Tue

EVALUATION OF GAIN IN ETL FEL OSCILLATION WITH OPTICAL KLYSTRON

Kiyoshi Yoshikawa, Satoshi Hashimoto, Masami Ohnishi, Yasushi Yamamoto
Institute of Atomic Energy, Kyoto University, Uji, Kyoto 611, Japan
Telephone: 0774-32-8154; Fax: 0774-33-1132
and
Tetsuo Yamazaki, Kawakatsu Yamada, Norihiro Sei
Electrotechnical Laboratory, Tsukuba, Ibaraki 305, Japan
Telephone: 0298-54-5541; Fax: 0298-52-7944

Abstract

A particle simulation code was developed for gain evaluation of the FEL oscillation by the optical klystrons in the ETL storage rings, TERAS, and NIJI-4.

The optical beam profile was assumed to be Hermite-Gaussian, and only the fundamental mode was considered based on the experimental results.

The effects of particle numbers, and the method of assigning initial conditions, in particular, in phase on the gain evaluation were examined. About 2000 electrons were found to be sufficient for reasonable gain evaluation when the quiet start scheme was adopted.

It was found also that the evaluated gains based on the present particle code, Madey's theorem, and Colson's analytical model all agree quite well with the gains evaluated in the TERAS experiments. For NIJI-4, where the overlap of the electron and optical beams is not considered ideal, the present particle code could have predicted quite reasonable gains which are in good agreement with the NIJI-4 experiments.

SIMULATION OF REVERSED AND CONVENTIONAL GUIDE FIELD OPERATION IN A FREE ELECTRON LASER

G. Renz and G. Spindler
German Aerospace Research Establishment (DLR)
Institut für Technische Physik
Pfaffenwaldring 38-40
70503 Stuttgart, Germany

An amplifier experiment done at MIT [1] shows, as compared to the conventional guide field orientation, higher electronic efficiency in the *reversed* case of operation.

Simulations of the electron dynamics within the framework of a single particle model have been done to compute the spontaneous emission and the electronic efficiency in the parameter regime of the MIT experiment. Waveguide effects and the self-fields of the electron beam are included. The paper concentrates on differences in the electron dynamics and the resulting radiation properties of the two operation modes. As an example, the small signal efficiency is found to be an order of magnitude higher for the reversed guide field orientation.

[1] M.E. Conde and G. Bekefi, Phys. Rev. Lett. *67*, 3082 (1991)

ELECTRONIC ORBITS IN A HELICAL WIGGLER WITH AXIAL GUIDE FIELD

J.T.DONOHUE and J.L.RULLIER[1]
Laboratoire de Physique Théorique
Université de Bordeaux I

Abstract

The electronic orbits in a helical wiggler with an axial guide field are studied in a three-dimensional Hamiltonien formalism. A primordial role is played by the conserved quantity corresponding to the screw-displacement symmetry of the magnetic field. Provided certain inequalities are satisfied by this variable, the reduced Hamiltonien has a fixed-point, wich corresponds to a centered helical orbit. Expansion of the Hamiltonien about the stable fixed-points leads, after canonical transformations, to a description of the motion in terms of two uncoupled harmonic oscillators, whose frequencies and normal modes may be calculated analytically. Provided the corresponding amplitudes of oscillation are not too large, a quantitavely correct description of the electronic trajectories is found. Among the original aspects of this work are the determination of the signs of the frequencies, and the phenomenon of repulsion of these last wich occurs when they attempt to cross as some parameter is varied. This is accompanied by a rapid cross-over of the coefficients of the normal modes, wich in turn leads to erratic behavior of the trajectories and consequently to decreases drastically the efficiency of the free electron laser.

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[1] Supported by CEA/CESTA, France.

INFLUENCE OF THE RADIATION FORCE ON FREE-ELECTRON LASER GAIN

A. V. Serov.

P. N. Lebedev Physical Institute Russia Academy of Sciences, Leninsky Prospect 53, Moscow, Russia.

An interaction between the beam and the wave in a free-electron laser has been investigated, taking into account the radiation force. Inclusion of the small effect of the radiation part of the Lorentz force on the electron motion is shown to modify free-electron laser gain. Relationship between the characteristic of the spontaneous emission and the effect of the radiation force on free-electron laser gain are derived.

Tu4–60

24Tue

SELECTED APPLICATIONS OF PLANAR PERMANENT MAGNET MULTIPOLES IN FEL INSERTION DEVICE DESIGN*

Roman Tatchyn

Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center, Stanford, CA 94309-0210, USA

Abstract

In recent work, a new class of magnetic multipoles based on planar configurations of permanent magnet (PM) material has been developed. These structures, in particular the quadrupole [1] and sextupole, feature fully open horizontal apertures, and are comparable in effectiveness to azimuthally symmetric iron multipole structures. In this paper results of recent measurements of planar PM quadrupoles and sextupoles are reported and selected applications to FEL insertion device design are considered.

[1] R. Tatchyn, "Permanent Magnet Edge-Field Quadrupoles As Compact Focussing Elements for Single-Pass Particle Accelerators", SLAC-PUB-6058, February 1993.

* Supported by DOE Offices of Basic Energy Sciences and High Energy and Nuclear Physics.

HYBRID MICROUNDULATOR DESIGN FOR THE CREOL COMPACT CW-FEL

Müfit Tecimer and Luis R. Elias
CREOL ,12424 Research Parkway, Orlando FL 32826, USA

Abstract

For the CREOL compact, cw - FEL several short-period, 6 - 8 mm, planar undulator design concepts have been studied. Short-period undulators offer the advantage of reduced electron beam energy and a compact FEL system to generate radiation at a given wavelength. The reduction in the undulator period length however imposes stringent requirements on mechanical alignement and magnetic material tolerances. The compensation of random field errors due to variations in the characteristics of available magnets necessitates a suitable magnet pairing process and a precise positioning technique. Two undulators were constructed and tested. The first undulator consists of twenty periods with 6 mm period length, the latter sixty two periods with 8 mm period length. Both were constructed from NdFeB magnet blocks with retractable vanadium permendur poles. The field tuning scheme used was able to reduce peak field errors from 8 % rms to 0.3 % rms and 2.5 % rms to 0.2 % rms respectively.

In order to operate the CREOL FEL [1] as a cw laser source, nearly 100 % of the electron beam must be recovered. The beam must pass through a 185 period undulator in a waveguide structure with 4 mm height. Based on measured field data, beam transport simulations have been performed to determine beam losses due to field errors and errors associated with possible misalignements of the undulator structure. Beam transport with current larger than 200 mA will also be discussed.

REFERENCES

[1] Luis R. Elias, Isodoro Kimel, Delbert Larson, Dan Anderson, Mufit Tecimer and Zhong Zhefu, Nucl. Inst. and Meth. A304, 219 (1991).

Magnetic measurements of a hybrid permanent magnet undulator for the LISA-SURF IR FEL experiment

L. Barbagelata, S. Curotto, M. Grattarola, G. Gualco, F. Rosatelli
Ansaldo Ricerche - Corso Perrone, 25 - 16161 Genova, Italy

F. Ciocci, A. Renieri
ENEA, Dipartimento Sviluppo Tecnologie di Punta
PO Box 65, 00044 Frascati, Roma, Italy

Abstract

The hybrid permanent magnet undulator for the LISA-SURF IR FEL experiment (INFN, Frascati, Italy) was designed and manufactured under a collaboration between Ansaldo Ricerche and ENEA. The magnetic field of the undulator was measured at Ansaldo laboratories by means of a Hall probe driven by a high precision positioning bench. The electron trajectory and the emission spectra were calculated from the measured magnetic field to verify the quality of the undulator. The uniformity and periodicity of the magnetic field required for FEL operation were obtained by means of both the accurate sorting of the permanent magnet blocks and the tight fabrication tolerances. Active and passive correction systems were used for a further improvement of the magnetic field quality. In particular, two end coils and a long dipole coil were used to correct the field integrals while iron shims were used to provide the local corrections of the trajectory. The measuring equipment, the results of the magnetic measurements and the effect of the iron shims on the final performance of the undulator are described.

PROBING TERAHERTZ ELECTRON DYNAMICS IN SEMICONDUCTOR NANOSTRUCTURES WITH THE UC SANTA BARBARA FEL

Jann Kaminski, S. James Allen, M. Sherwin, B. Keay, J. S. Scott, K. Craig, J. Heyman, P. Guimaraes
Center for Free-Electron Laser Studies
Quantum Institute
University of California, Santa Barbara
Santa Barbara, CA 93106-5100
Phone:(805) 893-3390 FAX: (805) 893-4170

The presentation will briefly describe the UC Santa Barbara (UCSB) FEL Experimental User Facility and report on some current research projects focusing on terahertz electron dynamics in semiconductor nanostructures.

For many years, there have been novel and exciting predictions concerning terahertz electron transport in semiconductor systems. Effects such as harmonic generation, self-induced transparency, miniband collapse, photon-assisted tunneling and non-perturbative energy level repulsion have generated a lot of theoretical activity. While these phenomena are potentially important for future terahertz semiconductor technology, they have not been addressed experimentally. The UCSB FEL facility which provides kilowatts of tunable radiation from 180 GHz to 4.6 THz is uniquely suited to address these issues.

We have recently enjoyed some success in the following areas:

1.) Dynamic localization in quantum well superlattices. The conductance of a multi-quantum well superlattice is shown to be an oscillatory function of the terahertz field strength. Although the mechanism is not clearly understood, the oscillatory conductance is a graphic demonstration of localization of carrier transport in a strong terahertz electric field.

2.) Photon-assisted sequential resonant tunneling. Photon-assisted tunneling, a phenomena readily associated with superconducting S-I-S tunnel junctions, is demonstrated for the first time in a semiconductor system.

3.) Saturated intersubband absorption below the LO phonon. The quantum well intersubband energy relaxation times below the LO phonon remains controversial and technically important for many proposals for intersubband lasers. Saturation spectroscopy enables us to measure the relaxation rates directly.

4.) Terahertz dynamics of resonant tunneling diodes. State-of-the-art resonant tunneling diodes (RTD) are thought to have intrinsic relaxation rates at terahertz frequencies. By measuring the rectified response from 200 GHz to 3.6 THz, we have directly measured the intrinsic relaxation time and the so-called "quantum inductance" in high speed RTD's.

The FEL as a tool for assessment of parameters in the medical use of lasers.

B.Jean[1], T.Bende[1], T.Seiler[2], Ch.Brau[3],
1) Div.Exp.Ophthalmic Surgery Univ.Eye Hospital Tübingen/FRG
2) Eye Clinic,Free University Berlin/FRG
3) Vanderbilt University, Free Electron Laser Center, Nashville TN

Although laser photoablation is the least invasive surgical procedure in various medical specialties, little is known about its physical principles. So far laser-tissue interactions and medical applications have been studied only at the emission wavelengths and parameters of available gasion or solid-state lasers.
Until now, medical applications based on the criteria of optimal photoablation for a given biological material at minimal side effects (thermal damage, shockwave etc.) have only been possible via an expensive "trial and error" procedure.
Only the FEL, which provides different combinations of wavelengths, pulslengths and energy, allows prospective studies of the optimal set of parameters for a given tissue.
For the cornea, as a typical soft tissue with high water content, photoablation was studied between 2,7µm and 6,7µm at the **Vanderbilt University FEL** with a constant fluence of 1,3 J/cm2 and a pulse duration of 4µs. Ablation zone diameter was 1 mm. Ablation was performed on gelatine (as a proven corneal model) and on porcine corneas. The ablation rates increased as absorption values rose. Ablation was possible over the entire wavelength range. At low absorption, ablation was achieved by increasing fluence (3,5 J/cm^2); leading to a very distinct thermal damage pattern. At the absorption maximum of 6.2µm, the ablation threshold is 0.6 $\pm$ 0.1 J/cm^2. At the same wavelength,variation of hydration (wet weight/dry weight) of the gelatine probes shows a maximal ablation rate at 2.1 J/cm^2. Increasing the laser repetition rate from 1 to 20 Hz also increases the ablation rate in dry gelatine from 4.3 to 7.5µm/pulse with the above laser parameters.
These results were applied to the far IR wavelength (17µm-150µm), provided by the **FELIX/FOM-Institute Rijnhuizen/NL**. At the absorption maximum of water around 17 µm and around 60 µm, photoablation was demonstrated for the first time; thermal damage was the lowest described so far for the IR.
The FEL allows a new approach in determining laser parameters prospectively for a given biological target material.

25Wed

We1-3

FREE ELECTRON LASER-INDUCED BLEACHING OF THE INTERSUBBAND ABSORPTION IN SEMICONDUCTOR QUANTUM WELLS

B. Murdin, M. Helm*, C.R. Pidgeon
Physics Department, Heriot-Watt University, Edinburgh EH14 4AS, Scotland, U.K.

K.K. Geerinck, N.J. Hovenier, W.Th. Wenckebach
Faculty of Applied Physics, University of Technology Delft, 2600 GA Delft, The Netherlands

A.F.G. van der Meer and P.W. van Amersfoort
FOM-Institute for Plasmaphysics Rijnhuizen, 3439 MN Nieuwegein, The Netherlands

25Wed

The far infrared free electron laser FELIX has been used to measure the nonlinear intersubband absorption in GaAs/AlGaAs multiple quantum wells. The GaAs wells are 270 Å wide, leading to a subband separation of 18 meV. At this photon energy, the free-electron laser is the only **tunable** high-intensity radiation source available. The samples were prepared with a metallic grating on the top surface, which enables coupling of the radiation to the subband transition in a normal-incidence geometry, and furthermore makes it possible to modulate the electron density with a proper gate voltage. A sensitive absorption measurement can be performed in this way. Complete bleaching of the absorption is achieved at an intensity $I = 100$ kW/cm^2. The intensity-dependent absorption is fitted with a homogeneously broadened two-level system, leading to a saturation intensity of $I_s = 10$ kW/cm^2, and a population lifetime, T_1, of 1 ps. This is shorter than the pulse length of the laser micro-pulse (10 ps), which justifies the steady-state analysis. A longer lifetime than this would not be measurable in such an experiment. On the other hand, this lifetime is shorter than expected, since the excited subband is located below the optical phonon energy, and thus, one would expect that only slow acoustic phonon emission take place. We suggest that the measured relaxation time is related to impurity-assisted intersubband scattering followed by further optical excitation above the optical phonon energy.

In the strong saturation regime ($I \sim 1$ MW/cm^2) the Rabi frequency is already larger than the inverse coherent time, T_2. This opens up the possibility of observing coherent nonlinear effects in future experiments.

*permanent address: Institut für Halbeiterphysik, Universität Linz, A-4040 Linz, Austria

ADSORBATE VIBRATIONAL SPECTROSCOPY BY IR-VISIBLE SUM-FREQUENCY GENERATION USING CLIO-FEL: CO FROM CH_3OH ON Pt AND H/Si(111)-(1X1)

A. Peremans, A. Tadjeddine, M. Suhren, P. Dumas, J. M. Berset, F. Glotin and J.-M. Ortega.
LURE-CNRS, Bâtiment 209D, 91405 Orsay, France.

Abstract :

The use of an infrared-FEL allows vibrational spectroscopy of adsorbates by ir-visible sum-frequency generation (SFG) beyond the frequency range accessible by conventional infrared lasers. We synchronise a frequency doubled mode-locked YAG laser (532 nm) to the CLIO-FEL presently tuneable from 2. to 15.5 µm.

SFG-vibrational spectra of two interfaces have been obtained :

1) Our SFG spectrum of Si-H strecth of H/Si(111)-(1x1) surfaces confirms previous data obtained by P. Guyot-Sionnest et al. [1].

2) Original in-situ SFG spectra of the adsorbed CO (around 5 µm) , at the electrochemical interface Pt/HClO4 solution containing CH3OH, suggests the predominance of linear bound species. Detailed studies are now in progress.

In the near future this adsorbed SFG-vibrational spectroscopy will be extended toward longer wavelengths in order to study various interfaces and surfaces.

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25Wed

FREE-ELECTRON LASERS AND SEMICONDUCTOR PHYSICS: FIRST RESULTS ON INTERFACES AND NON-LINEAR OPTICS

G. Margaritondo, C. Coluzza, E. Tuncel, J. L. Staehli, F. Gozzo, P. A. Baudat, D. Martin, F. Morier-Genoud, C. Dupuy, A. Rudra and M. Ilegems
Ecole Polytechnique Fédérale, CH-1015 Lausanne, Switzerland

J. T. McKinley, A. Ueda, A. V. Barnes, R. G. Albridge, X. Yang, and N. H. Tolk
Department of Physics and Astronomy, Vanderbilt University
Nashville, Tennessee 37235.

Although free-electron lasers (FEL's) have been available in principle for some time, practical experimental results are still quite scarce. We recently initiated a systematic program of FEL spectroscopy on semiconductors and their interfaces. We are now happy to announce the first positive results of the program, in the areas of accurate interface energy barriers measurements and of two-photon absorption.

The program is supported by the recently commissioned Vanderbilt free-electron laser (FEL). Its first part concerns high-accuracy measurements on semiconductor interfaces using the FEL-Internal Photoemission (FELIPE) technique. This technique consists of deriving interface energy barriers such as Schottky barriers or heterojunction band discontinuities from photocurrent thresholds. It can reach very high accuracy (a very few meV), high reliability, and it can be applied to buried interfaces of realistic devices.

The first successful tests of this technque produced excellent results on binary and ternary III-V systems, as well as on systems involving amorphous group-IV semiconductors. The results already exceed the expectations, and their accuracy is better than that of standard techniques like photoemission by 2-3 orders of magnitude.

The second part of the program studies the two-photon absorption spectra of semiconductors. We succeded, two decades after the most recent attempt, in measuring the indirect two-photon absorption threshold of germanium. This phenomenon is a weak three-particle process, whose study was allowed by the superior intensity of the FEL. The results provide a long-delayed positive test of the Bassani-Hassan theory for this class of phenomena.

Wel–6

NONLINEAR OPTICS WITH A FREE-ELECTRON LASER

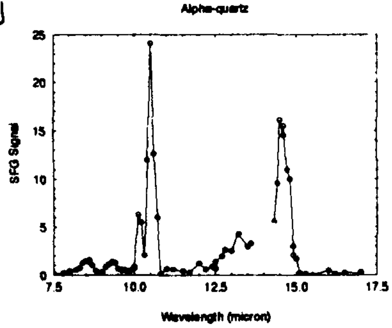
E.R. Eliel and Q.H.F. Vrehen
Huygens Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, the Netherlands

M. Barmentlo and G.W. 't Hooft
Philips Research Laboratories, P.O. Box 80000, 5600 JA Eindhoven, the Netherlands

A.F.G. van der Meer and P.W. van Amersfoort
FOM-Institute for Plasma Physics 'Rijnhuizen', P.O. Box 1207,
3430 BE Nieuwegein, the Netherlands

Nonlinear optical techniques are noninvasive tools that are widely applied to the study of surfaces and interfaces, in particular to surfaces covered with a (sub)monolayer of molecules. One of these, i.e., infrared-visible sum-frequency generation (SFG) promises to be an almost ideal tool for the study of such molecule-covered interfaces as it combines surface specificity with spectroscopic selectivity. The latter arises because the surface nonlinearity is resonantly enhanced when the infrared is tuned to a molecular vibrational resonance. Many molecules have their spectroscopic fingerprint in the mid-infrared; in this spectral region traditional laser setups are not sufficiently powerful or lack sufficient wavelength tunability for SFG experiments. Free-electron lasers (FELs), being extremely widely tunable and powerful lasers are believed to be eminently suited for infrared-visible SFG. We report on the first spectroscopic experiment on SFG with a FEL, in casu the Free-Electron Laser for Infrared eXperiments (FELIX) at Rijnhuizen. In this experiment the outputs of FELIX and a standard pulsed visible laser are mixed on the surface of simple crystalline solids. The measured SFG spectra (see Fig. 1a) reflect both the linear and nonlinear optical response at the interface that both strongly vary when a material resonance is hit. These narrow material resonances can only be studied in detail when the bandwidth of FELIX is at its narrowest ($\Delta\lambda/\lambda < 1\%$). These preliminary experiments, so far covering the 7-30 μm wavelength range, demonstrate that FELIX is eminently suited for this type of experiments. Major improvements in signal to noise are expected when a visible laser system will be available with a timing structure closely mimicking that of FELIX (see Fig. 1b).

a)



b)

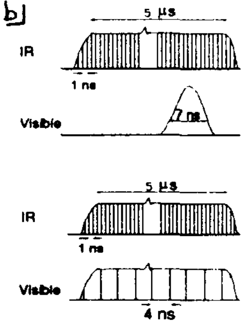


Figure 1: a) *IR-visible sum-frequency signal from α-quartz as a function of the IR wavelength. b) Timing structure of the two lasers in present (upper panel) and future (lower panel) experiments.*

25Wed

FREE-ELECTRON LASER POWER BEAMING TO SATELLITES AT CHINA LAKE, CALIFORNIA

H.E. Bennett
Research Department, Naval Air Warfare Center Weapons Division
China Lake, California 93555-6001

John D.G. Rather
NASA Headquarters
Washington, DC 20546

and

E.E. Montgomery IV
NASA Marshal Space Flight Center
Montgomery, AL 35812

25Wed

ABSTRACT

Laser power beaming of energy through the atmosphere to a satellite can extend its lifetime by keeping the satellite batteries in operating condition. Alternate propulsion system utilizing power beaming will also significantly reduce the initial insertion cost of these satellites, which now range from \$70,000 to \$160,000/kg, into geosynchronous orbit. Elements of power beaming system are a high power free-electron laser, a large diameter telescope to reduce diffractive losses, an adaptive optic beam conditioning system and possibly a balloon or aerostat carrying a large mirror to redirect the laser beam to the satellite after traversing the earth's atmosphere. China Lake, California has excellent seeing, averages 260 cloud-free days/year, has a large geothermal plant nearby for inexpensive power, the lake for water, and is thus an ideal site for such a laser power beaming system. Technological challenges in building such a system and installing it at China Lake will be discussed.

We2-2

PHOTOLUMINESCENCE AS A PROBE OF THE INTERACTION OF INTENSE FAR-INFRARED RADIATION WITH SEMICONDUCTOR QUANTUM STRUCTURES

P.C. van Son*, J. Cerne, M.S. Sherwin, and S.J Allen Jr.
Department of Physics and Center for Free Electron Laser Studies
University of California, Santa Barbara, CA 93106

M. Sundaram and I.-H. Tan
Materials Department and Department of Electrical and Computer Engineering
University of California, Santa Barbara, CA 93106

D. Bimberg
Technische Universität Berlin, Institut für Festkörperphysik I,
Hardenbergstrasse 36, D-1000 Berlin 12, Germany

25Wed

Photoluminescence (PL) is a very useful technique for studying quantum wells and other quantum confined semiconductor structures because of its selectivity and high sensitivity. We use PL to detect the effect of intense far-infrared (FIR) radiation on photo-excited electrons and holes in GaAs/AlGaAs quantum wells and quantum wires. At the UCSB FEL, which provides up to 20 μs long, 6kW pulses at wavelengths between 60 μm and 2 mm, a set-up has been realized to measure the PL spectrum while the FIR pulse is irradiating the sample.

Two distinct effects are expected to lead to changes in the PL spectrum. First, absorption of the FIR radiation will lead to a change in the amplitude of the peak(s). This effect may either be non-resonant (carrier heating) or resonant with a specific transition of the electrons or holes in the quantum confined structure. At the low-energy end of the PL spectrum the intensity decreases while the luminescence at higher energies increases, reflecting the change in the carrier distribution. Second, the ac electric field strength of the FIR radiation is large enough to cause changes in the energy levels of the electrons and holes (ac-Stark shift). This effect is expected to cause the PL spectrum to shift with increasing FIR intensity.

Experimental results have been obtained using regular quantum wells, parabolic quantum wells, and strain-induced quantum-well wires. In all cases the observed changes in the PL spectra could be attributed to non-resonant carrier heating. For the quantum wells, the peak(s) in the PL spectra did not shift, indicating that the lattice temperature (which determines the bandgap) did not rise much above its equilibrium value of 10 K. The amplitudes of the peaks however correspond to a carrier temperature of up to 100 K at the highest FIR intensity. For the quantum wires both the amplitude and the position of the PL peak change due to the FIR irradiation. However, a more careful look at the temperature dependence of the PL spectrum shows that apart from the well-known shift due to the temperature dependence of the bandgap, there is an additional, partly compensating shift. It is the latter shift that is observed during the FIR pulse. It can therefore be attributed to the increase of the carrier temperature although the exact mechanism is not clear yet.

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*Permanent address: Department of Applied Physics, Delft University of Technology, Lorentzweg 1, NL 2628 CJ Delft, The Netherlands.

MEASUREMENT OF SINGLE-PULSE SPECTRA OF AN INFRARED FEL*

W.P. Leemans, J.A. Edighoffer, K.-J. Kim, S. Chattopadhyay
Lawrence Berkeley Laboratory, University of California, Berkeley CA 94720
(510) 486 - 7788
and
H.A. Schwettman
W.W. Hansen Experimental Physics Laboratory
Stanford University, Stanford, CA 94305 - 4085, USA
(415) 723 - 0305

ABSTRACT

A novel diagnostic system [1] has been used to measure the spectra of infrared pulses generated by the Free Electron Laser (FEL) at Stanford University. The FEL operates in the wavelength range from 3 - 12 μm. The pulses have a duration of about 3 ps and are repeated at 12 MHz inside a macropulse which lasts typically 10 ms with a repetition rate of 10 Hz. The diagnostic system makes use of a high resolution 1 m spectrometer and an imaging system based on an image dissector [2] and a single element HgCdTe - high speed detector with integrating sphere. The diagnostic has allowed us to measure, for the first time, the evolution of FEL spectra on a micropulse-to-micropulse basis.

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25Wed

F. =QUENCY SHIFTING PHENOMENA IN FREE-ELECTRON LASERS

Gennady Shvets and Jonathan S. Wurtele

Department of Physics and Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge MA 02139

Frequency shifting in free-electron laser (FEL) oscillators and amplifiers is investigated theoretically and numerically. The analysis includes frequency shifts from the resonant FEL interaction and the nonresonant beam dielectric. Expressions for the frequency shift in a microwave amplifier with time-dependent beam energy and current are derived and found to be in good agreement with experimental observations by Conde, Bekefi, and Taylor. The theory shows that temporal changes in the detuning are the dominant factor in determining the frequency shift. Electron energy fluctuations produce frequency shifts in the Compton regime, while both current and energy variations are significant in the Raman regime. The effect is particularly important for high power microwave drivers proposed for high gradient accelerators, where the phase of the RF is subject to tight constraints. FEL oscillator response to variations in beam energy is examined. It is shown that in a low gain oscillator which experiences a sudden jump in beam energy the FEL creates spikes, at the head and tail of the beam, which are at the shifted frequency. The shifting is generated by time-dependence in the dielectric function which arises from slippage and finite lengths of the electron or optical pulse. A diffusion equation is derived and shown to describe the propagation of the spikes into the main body of the pulse.

SURFACE QUASI-CHERENKOV FEL

Baryshevsky V.G., Batrakov K.G., Dubovskaya I.Ya.

Institute for Nuclear Problems, Bobruiskaya 11, 220050, Minsk, Republic of Belarus

A scheme of a solid state (crystal) FEL on the basis of quasi-Cherenkov (parametric) radiation with distributed feedback was earlier suggested in [1]. However, multiple scattering is known to destruct the synchronism condition between a particle beam and an emitted electromagnetic wave. This leads, in its turn, to the essential enhancement of threshold parameters. Reduction of multiple scattering influence is possible through the transition to a surface geometry. In this case a particle beam moves over a periodic target boundary at a distance of $L \leq \lambda\gamma$ (λ is the wave length, γ is the Lorents factor) or at a small angle relative to this target [2].

This report is devoted to the consideration of induced radiation generation by a relativistic particle beam moving inside a channel with $\rho \simeq \lambda\gamma$ which is made in a periodic medium or over a periodic target surface. It is shown that, in the contrary to parametric spontaneous radiation, when the process inside a such channel develops in the same way as inside a periodic medium, the generation process of induced quasi-Cherenkov radiation is possible only by a relativistic particle beam in a longitudinal magnetic field. The threshold values of generation parameters and spectral-angular distribution of coherent surface quasi-Cherenkov radiation are derived. It is analyzed the possibility of induced radiation generation for different spectral ranges. Two opposite generation regimes are considered: the limits of "hot" and "could" particle beams.

26Thu

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SUPPRESSION OF THE SIDEBAND INSTABILITY IN TAPERED FELs AND IFELs

A. Bhattacharjee and Ravi P. Pilla

Department of Applied Physics
Columbia University
500 West 120th Street
New York, New York 10027

It is well known that tapered wigglers can improve the efficiency of FELs significantly. Recently, it has been discovered by experiments (Yee, Marshall and Schlesinger, 1988) and numerical simulations (Hafizi et al., 1988) that in addition to efficiency enhancement, tapering can lead to a strong suppression of the sideband instability. In this paper, we give an analytical theory for this phenomenon. As a further application of the theory, we demonstrate that strong suppression of sidebands also occurs in an IFEL in which tapered wigglers are required in order to obtain significant acceleration of particle beams.

The theoretical analysis is carried out (in the laboratory frame) for a deeply-trapped electron bunch in a tapered FEL, and yields an algebraic fourth-order equation for sideband modes. Analysis of the dispersion equation shows that due to the presence of the taper, the frequency of the sidebands with peak growth rates change continuously along the wiggler. Consequently, no sidebands are allowed to grow to significant amplitudes though the sideband spectrum itself is broad. The pre-bunched particles remain deeply trapped, and loss of efficiency due to separatrix crossings do not occur. By an optimum choice of wiggler parameters, it is possible to obtain 70% extraction efficiencies with the sideband intensities suppressed by eight orders of magnitude with respect to that of the primary laser frequency. The dispersion equation for the IFEL, though qualitatively different, shows a similar degree of suppression.

This research is supported by the DOE and the ONR.

SUPERRADIANCE OF ENSEMBLES OF CLASSICAL ELECTRON-OSCILLATORS AS A METHOD FOR GENERATION OF ULTRASHORT ELECTROMAGNETIC PULSES

N.S. Ginzburg, Yu.V.Novozhilova, A.S. Sergeev

Institute of Applied Physics, Russian Academy of Science,
46 Uljanov Str., 603600 N.Novgorod, Russia

The effects of the superradiance of ensembles of inverted atoms in quantum electronics have long been an object of theoretical and experimental investigations [1,2]. Recently, interest was aroused in such phenomena in ensembles of classical oscillators [3-8]. A classical analogue of the superradiance effect is radiative instability in space-localized ensembles of electron-oscillators having infinite lifetime. Development of nonthreshold superradiative instabilities results in radiation of the energy of oscillatory motion in the form of short electromagnetic pulses.

In the report superradiance in the layer of electron moving in an undulator field or rotating in a uniform magnetic field is investigated. It is shown that the superradiance effects may by used for generation of powerful ultrashort microwave pulses. For example, in the millimeter wavelength range it is possible to generate gigawatt pulses with duration about several period of HF oscillations.

Powerful ultrashort microwave pulses are interesting for radiotechnical applications, as well as for investigations of nonlinear phenomena in plasmas and solid matter.

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ELECTRON TRAJECTORIES IN A FREE ELECTRON LASER WITH A REVERSED AXIAL GUIDE FIELD

A. Bourdier[*], V.A. Bazylev[**], Ph. Gouard[+], J.M. Buzzi[++]

[*]C.E.A. / PTN - 91680 Bruyères-le-Châtel, France
[**]I.V. Kurchatov Institute of Atomic Energy - Moscow, Russian Federation
[+]C.E.A. / CEL-V - 94195 Villeneuve-Saint-Georges Cedex, France
[++]Laboratoire de Physique des Milieux Ionisés, Centre National de la Recherche Scientifique
Ecole Polytechnique, 91128 Palaiseau Cedex, France

In order to interprete the experiment of Conde and Bekefi, electron trajectories are studied for a configuration with a reversed axial guide field. First, ignoring the radial dependence of the wiggler, an analytic model is constructed. The results are discussed and compared with those of numerical simulations. Close to "anti-resonance", two types of electron trajectories are considered and discussed. One type corresponds to a linearly polarized motion and leads to a moderate coupling with the radiation field. This first part shows how electrons, which remain close to the axis of the beam, can contribute to the dip in the power output observed. Then, the radial dependence of the wiggler is considered. In the victinity of "anti-resonance", electrons are shown to have "chaotic" trajectories when emitted far enough from the axis. As a consequence the interaction efficiency is degraded for most paricles. This explains the large dip in radiative power observed and predicted with our simulation code. The radial dependence also gives a possible explanation for the very good efficiency observed in the experiment.

[*] Also in Laboratoire de Physique des Milieux Ionisés, Centre National de la Recherche Scientifique Ecole Polytehnique, 91128 Palaiseau Cedex, France

An Eight Centimeter Long Accelerator for a Far Infrared FEL

J.F. Schmerge, J.W. Lewellen, Y.C. Huang,
J. Harris, J. Feinstein, L. Zitelli, R.H. Pantell

McCullough 310
Electrical Engineering Department
Stanford University
Stanford CA 94305, USA

If the FEL is ever to become a reasonably common laboratory item, then it must be compact, inexpensive, reliable, simple to use, and operate in a region of the spectrum where there are interesting applications and few alternative sources. A candidate for this role is a far infrared oscillator using a thermionic gun in an rf cavity.

A critical question is whether or not the beam characteristics (i.e. emittance, energy spread, current, micropulse duration) from such a gun are suitable to provide sufficient gain for an oscillator. We have been studying a one-and-one-half cavity rf gun accelerator, using computer simulations to predict energy spread, emittance and pulse duration during a micropulse, and measuring the energy spectrum and emittance on a macropulse time scale.

The acceleration length is 7.8 cm, with a high shunt impedance of 135 MΩ/m, so that high acceleration gradients are attainable. For example, with a macropulse current of 0.5A out of the gun, an input power of 4.0MW produces 3.5 MeV electrons, and 5.5 MW input gives 4.2 MeV electrons. For our wiggler, which has a period of 1.0 cm and $a_w = 0.7$, the FEL oscillation wavelengths are 122 μm and 88 μm, respectively. The gun is powered by an S-band klystron operating at a wavelength of 2.856 GHz.

Measurements have been made of the energy spectrum and beam emittance using 1% energy filtering, which is a reasonable energy spread from the standpoint of FEL interaction. We have obtained up to 30% of the electrons through 1% slits, corresponding to a peak micropulse current of 5A, with a normalized emittance of 8πmm-mrad. To realize maximum current, magnetic deflection was used in the gun to reduce back bombardment heating of the cathode.

The latest measurements will be presented for the energy spectrum and emittance as functions of beam current and energy, along with the predicted performance of a far infrared FEL oscillator.

26Thu

A NOVEL LASER DRIVEN RF STRUCTURE FOR THE GENERATION OF BRIGHT ELECTRON BEAMS

L.Serafini
INFN and Universita' di Milano
Via Celoria 16 - 20133 Milano -Italy

Most of X-UV FEL schemes proposed so far need intense and bright electron beams as the ones typically delivered by laser driven RF injectors. It is well known that the lower the radiation wavelength the tighter are the beam requirements in terms of peak current, emittance and energy spread. In this paper we present a novel RF gun structure suitably designed for the exploitation of the disk bunch technique. Recently proposed§, this technique is based on the neutralization of the space charge induced emittance growth, achieved via an optimum intensity distribution profile of the laser pulse illuminating the cathode. In order to obtain the maximum benefit, in terms of beam quality, from this technique, we designed and carefully tested by accurate PIC simulations a novel RF gun structure, based on a slotted cylindrical wave guide connected to a coaxial line. Such a structure allows to minimize the non linear transverse RF components, that are responsible for the residual emittance blow-up when the disk bunch technique is applied within a standard (Brookhaven like) RF gun structure. The proposed novel structure exhibits a decrease of the shunt impedance, with respect to standard rf guns: this disadvantage is well compensated by an increase of more than one order of magnitude in the beam brightness achievable.

§ L.Serafini, Proc. of 3rd Int. Workshop on Advanced Accelerator Concepts, Port Jefferson (NY), June 1992

PERFORMANCE OF THE HIGH BRIGHTNESS LINAC FOR THE ADVANCED FREE-ELECTRON LASER INITIATIVE AT LOS ALAMOS*

R. L. Sheffield, R. H. Austin, B. E. Carlsten, K. D. C. Chan, W. J. D. Johnson, S. M. Gierman, J. M. Kinross-Wright, S. H. Kong, K. L. Meier, J. G. Plato, D. C. Nguyen, S. J. Russell, B. A. Sherwood, C. A. Timmer, M. E. Weber, and L. M. Young
Los Alamos National Laboratory, Los Alamos, NM 87545

The AFEL accelerator has produced beams of greater than 3×10^{12} A/m^2 at 1 nC (brightness = $2*I/\varepsilon^2$, with I greater than 100 A and ε of 1.5 π mm-mrad normalized rms emittance). The 1300 MHz standing-wave accelerator uses on-axis coupling cells. The electron source is a photoinjector with a CsK_2Sb photocathode. The photoinjector is an integral part of a single 11-cell accelerator structure. The accelerator operates between 12 and 18 MeV. The beam emittance growth in the accelerator is minimized by using a photoinjector, a focusing solenoid to correct the emittance growth due to space charge, and a special design of the coupling slots between accelerator cavities to minimize quadrupole effects. This paper describes the experimental results and compares those results with PARMELA simulation, which was modified for this effort. This modified version uses SUPERFISH files for the accelerator cavity fields, MAFIA files for the fields due to the coupling slots in the accelerator cells, and POISSON files for the solenoid field in the gun region.

*Work performed under the auspices of the US D.O.E. and funded by LANL Laboratory Directed Research and Development.

DEVELOPMENTS ON THE TEUFEL INJECTOR RACETRACK MICROTRON

J.I.M. Botman, J.L. Delhez, H.L. Hagedoorn
W.J.G.M. Kleeven, C.J. Timmermans and G.A. Webers,
Eindhoven University of Technology, P.O. Box 513,
5600 MB Eindhoven, Netherlands

and

G.J. Ernst, J.W.J. Verschuur and W.J. Witteman,
Twente University, P.O. Box 217,
7500 AE Enschede, Netherlands

In this paper we report on developments of the 25 MeV racetrack microtron (RTM) that will be the electron source for the second phase of the TEUFEL project, to generate radiation of 10 μm in a 2.5 cm period hybrid undulator.

The theoretical understanding of this unconventional, azimuthally varying field type of RTM has been extended; a comparison of theoretically calculated orbit stability with that based on measured data will be presented. In particular, magnetic field measurements have been performed on the inhomogeneous sector magnets. Orbit calculations using measured field data show the designed performance.

Construction and tuning of the 1300 MHz, 2.2. MV microwave cavity have been completed, and signal level measurements have been performed.

The overall assembly of the microtron is nearing completion. At present a vacuum pressure better than $5 \cdot 10^{-7}$ Torr is achieved.

A design for the transfer line from the 6 MeV injector linac to the RTM will be shown.

MAGNETIC BUNCHING EXPERIMENTS ON ELSA

S. Joly, D.H. Dowell and the ELSA-FEL Team

Commissariat à l'Energie Atomique

B.P. N°12, 91680 Bruyères-le-Châtel, FRANCE

Abstract

A non-isochronous beam transport system can be used to reduce the pulse length of an electron beam with the proper correlation in energy and time. Performing magnetic bunching at relativistic beam energies, achieves a high-peak current while minimizing emittance growth due to space charge forces. When combined with the RF gun photocathode injector, magnetic bunching has the potential to produce an electron beam with the low transverse emittance and high-peak current necessary for efficient free-electron laser operation. The ELSA RF photocathode accelerator beamline contains a 180 degree, three dipole, non-isochronous bend which has been used to bunch the electron beam. A compression factor of about 3 has been achieved in preliminary tests. Pulse length measurements over a range of compression factors can provide the longitudinal emittance using an analysis technique similar to that for the transverse emittance. Experimental results of beam bunching, the longitudinal emittance determination and growth of the transverse emittance during bunching will be presented. The effect upon ELSA FEL performance will be described.

SINGLE BUNCH INJECTION OF THE STORAGE RING NIJI-IV FOR FEL

M. Yokoyama, M. Kawai, S. Hamada and K. Owaki
Kawasaki Heavy Industries, Ltd.
1-1, Kawasaki-cho, Akashi, Hyougo, 673, Japan

T.Yamazaki, T. Mikado, K.Yamada, N. Sei, S. Sugiyama, H. Ohgaki, T . Noguchi, R. Suzuki and M. Chiwaki
Electrotechnical Laboratory
1-1-4, Umezono, Tsukuba, Ibaraki, 305, Japan

T. Tomimasu
Free Electron Laser Research Institute Inc., 2-7-4,Kyomachibori, Nishi-ku, Osaka, 550, Japan

The storage ring "NIJI-IV" dedicated to FEL was constructed in December 1990. The first lasing at 595nm and an experimental set up on NIJI-IV for FEL have been reported in the 14th FEL conference. Moreover on 18 September 1992 FEL lasing at 488nm has been accomplished. At present, preparations for a FEL experiment in UV region is being made.

The electron bunch contributed to FEL gain of NIJI-IV is only one of 16. In order to get rid of the redundant bunches and make beam quality better, a single bunch injection system by using a short pulse beam from an electron gun is under preparation. It is expected that the injection system provides higher peak current and easier FEL operation in comparison with the previous rf-KO system.

The performance of the single bunch injection system and results of experiment by using it will be reported in this conference.

Progress report of the FEL injector at CIAE

W.Z.Zhou, T.L.Yang, X.L.Zhai, X.Z.Shi,

Z.M.Jin, D.X.Pu, Q.Sun, Y.Z.Lu, W.K.Chen

China Institute of Atomic Energy

P.O.Box 275, Beijing 102413 China

Abstruct

An L–band FEL injector with one electron gun. one subharmonic prebuncher (108MHz) and one buncher (1300MHz) in CIAE for scientific research has been built before the beginning of 1992. at the present the testing of the injector has been given some results and a coved cavity accelerating section with 20MeV is *developing now*.

26Thu

A 5-MeV ELECTRON INJECTOR AND THE FELI LINAC

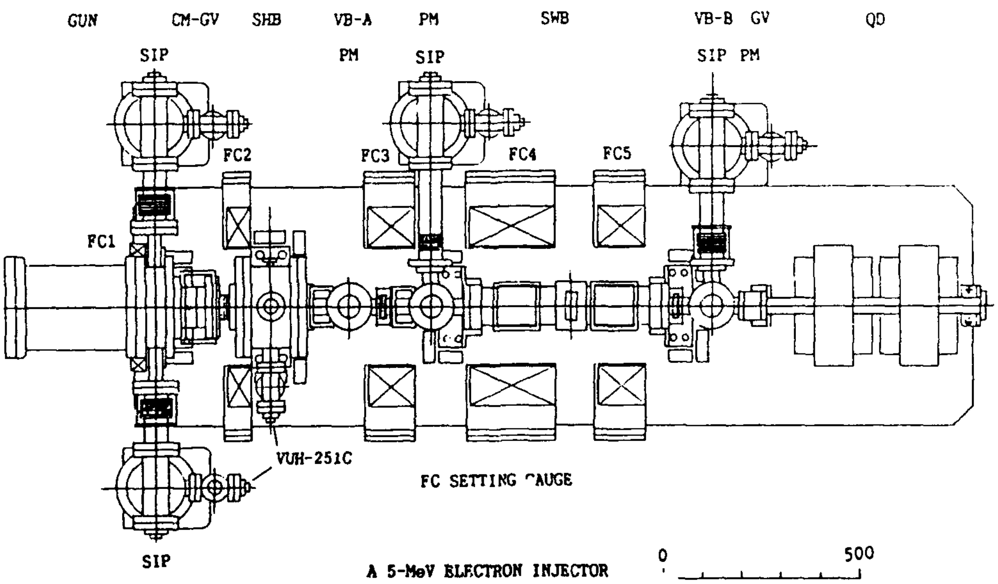
T. TOMIMASU, Y. MORII, A. KOGA, Y. MIYAUCHI, S. SATO, T.KEISHI,
S. ABE, A. KOBAYASHI, I. BESSHO and A. NAGAI

Free Electron Laser Research Institute, Inc. (FELI)

Kyomachibori 2-7-4, Nishi-ku, Osaka 550, JAPAN

Telephone:06-449-5903, Telefax:06-449-5911

FELI is aiming at IR-FEL generation by the end of 1994 using an 80-MeV beam and 2-m long undulator and UV-FEL generation by the end of 1996 using a 170-MeV beam and 3-m long undulator. The layout of a 5-MeV electron injector for FELI linac is shown below. It consists of a 150-keV DC thermoionic triode gun operated by a 178.5-MHz 500ps pulser (Kentech Instruments, Ltd.), a 714-MHz prebuncher (SHB) made of stainless steel, a 2856-MHz standing wave type buncher (SWB), a current monitor, three beam position monitors (PM), two gate valves (GV), five focusing coils (FC), and ten steering coils. The distance from the gun cathode (EIMAC Y646B) to the buncher is about 80cm. The maximum focusing field is about 0.18T near SWB.



A 5-MeV ELECTRON INJECTOR

NEW SEMICONDUCTOR SPECTROSCOPY AND ABLATION STUDIES WITH THE VANDERBILT FREE-ELECTRON LASER

Norman Tolk, Royal Albridge, Allan Barnes,
Giorgio Margaritondo, Jim McKinley and Akira Ueda
Center for Molecular and Atomic Studies at Surfaces
Department of Physics and Astronomy
Vanderbilt University, Nashville, TN 37235

Heterojunction band discontinuity measurements have been carried out with unprecedented accuracy using the recently commissioned Vanderbilt Free-Electron Laser. The Vanderbilt FEL, the most powerful tunable FEL in the world, is uniquely equipped for the spectroscopy of semiconductor systems due to its brightness, tunability and infrared spectral range, 1-8 μm (0.15-1.2 eV). In this presentation, we report the results of free-electron laser internal photoemission (FEL-IPE) measurements of conduction band discontinuities at GaAs/GaAlAs, InP/GaInAs, and GaAs/a-Ge interfaces and discuss the application of both this technique and fluorescence/absorption spectroscopies to the determination of the electronic properties of nano- and meso-structures. Our measurements are accurate to better than ±5 meV.

As will be discussed, FEL-IPE is a *direct* measurement of the discontinuity, a photocurrent occurs if the photon energy exceeds the conduction band discontinuity. No complex modeling is required: the discontinuity is given by the photocurrent threshold energy. Because of the FEL's broad tunability, the IPE technique is applicable to most technologically interesting semiconductor interfaces. Both linear and Fowler curve fits yield photocurrent threshold energies that agree within 5 meV. Conventional vacuum photoemission agrees with our measurements to within the accuracy of vacuum photoemission (±100 meV). Unlike vacuum photoemission, which must be applied to *immature* interfaces that are within a few monolayers of a surface, FEL-IPE can be used to measure the discontinuities at buried device-quality heterojunctions deep beneath a surface. FEL-IPE is a significant advance over conventional IPE, which uses a visible lamp to induce electronic transitions from the valence band of one material to the conduction band of the other. The conduction band discontinuity is given by the threshold photon energy minus the interface band gap.

The intense radiation produced by an FEL is particularly useful in wavelength-dependent photodamage and ablation studies of semiconducting and insulating materials. For example the massive ablation threshold in polycrystalline CVD-grown diamond films has been observed to be highly wavelength dependent near the C-H stretch absorption band at 3.47 μm. This demonstrates strong wavelength dependence in the mechanisms leading to the early phases of ablation. In previous photodesorption studies of alkali halides, the degree of excitation-localization has proven critically important in developing microscopic models of the desorption. We address this issue in the diamond studies by comparing photodesorption near the C-H stretch mode (which is localized around hydrogen impurities) to photodesorption in the vicinity of the 2-phonon absorption band at 4-6 μm (which is a delocalized excitation).

Future research will employ the high brightness of the FEL which is necessary for the studies of ultra-small systems (nano-Schottky barriers, multiple quantum wells, quantum wires, and quantum dots) in order to achieve adequate signal level. We gratefully acknowledge support by the Office of Naval Research under Grant N00014-91-J-4040 and partial support under Contract N00014-91-C-0109.

26Thu

Industrial Applications of Free Electron Lasers

by J. Lucas and R.A. Stuart
Department of Electrical Engineering and Electronics
The University of Liverpool
P.O. Box 147, Liverpool, L69 3BX, UK

ABSTRACT

The Free Electron Laser (FEL) has been developed to the point where it is capable of generating laser radiation in the waveband between 10mm to 100μm and even shorter wavelengths. This waveband and the kilowatts of power available from an FEL means that the FEL is potentially capable of being used for industrial material processing. The current market for CO_2 lasers and laser systems was estimated in 1991 to be approximately \$120M. This is for laser equipment working at 10.6μm wavelength and 1-10kW power. An overlap into this market is thus foreseen.

In competition with other lasers, such as the CO_2 and YAG lasers, the FEL has two significant advantages; they are readily tunable within a very wide frequency range and can be engineered to produce very high powers with relatively straightforward engineering. Thus if all else is the same the FEL would be the preferred laser. The subject thus hinges on whether the FEL can be made small enough, reliable enough and of high enough beam quality. In all these areas significant advances have been made by the Liverpool group.

In competition with other energy sources for the processes of cutting, welding, surface treatment, drying, cooking and spot heating, the introduction of powerful lasers is opening up new markets and displacing processes of inferior quality or speed. There is no reason why the FEL should not compete equally successfully. The problem here depends on whether the price is competitive. In common with other lasers there is nothing intrinsically costly in the construction of an FEL and thus price is a strong function of the market size.

Potential applications in the waveband 10mm to 100μm have been considered. These include applications with solid inorganic materials, solid organic materials and liquid materials. The inorganic materials considered are metals, glass, ceramics and concrete whilst the organic materials which have been considered are paints and plastics. Applications discussed for liquid materials include pasteurisation, and sterilisation, glue softening and setting, crystallisation processes and casting processes.

COMPACT WAVEGUIDE FEL FOR SPECTROSCOPIC MEASUREMENTS IN MUONIC HYDROGEN

F.Ciocci, F.Della Valle, A.Doria, G.P.Gallerano, L.Giannessi, E.Giovenale, P.Hauser**, F.Kottmann**, G.Messina, E.Milotti*, C.Petitjean**, L.Picardi, A.Renieri, C.Rizzo*, C.Ronsivalle, L.M.Simons**, D.Taqqu**, A.Vacchi*, A.Vignati, E.Zavattini**

ENEA, Area INN, Dipartimento Sviluppo Tecnologie di Punta
P.O. Box 65 - 00044 Frascati, (Rome) Italy. Tel:+39-(6)-94001

Recently a spectroscopy experiment on muonic hydrogen has been proposed by INFN-Trieste to test the QED radiative corrections in a lepton-hadron bound system. The experiment, to be performed at Paul Scherrer Institut in Villigen (CH) where a high intensity muon beam is available, is based on the irradiation of the excited muonic atom during its formation, with an intense, tunable laser radiation in the Far Infrared.

The short muon life time and the high accuracy required in measuring the energy difference between levels of muonic hydrogen, having at the same time a reasonable event rate, set a number of severe requirements on the FIR radiation source needed for the experiment. The tunability and pulse duration requirements, in particular, rule out the possibility of using a conventional laser source, and leave as only possible solution the choice of a Free Electron Laser.

The FEL source should satisfy several strong requirements that can be summarised as follows: a) The FEL has to be triggerable within a time less than 1.5 μs after the muon detection to excite the muonic hydrogen during formation. b) Tunable operation around the two wavelengths 232 μm and 532 μm, corresponding to the 3P-3D and 4P-4D transitions respectively, is required; a typical tuning range would be ± 1%. c) A linewidth of about $5 \cdot 10^{-3}$ is required with a corresponding pulse duration ≥ 100 ps. In this wavelength region a compact FEL can be realised according to the previous criteria. The design characteristics and experimental issues of this source will be presented.

* Istituto Nazionale di Fisica Nucleare Sezione di Trieste, I-34127 Trieste, Italy
** Paul Scherrer Institut, CH-5232 Villigen, Switzerland

Th3–15

RECENT RESULTS OF THE ELSA-FEL

S. Joly, Ph. Guimbal and the FEL Team

Commissariat à l'Energie Atomique
B.P. N° 12, 91680 Bruyères-le-Châtel, FRANCE

ABSTRACT

The ELSA-FEL has been improved this year by changing some of the drive laser components and the optical cavity parameters. Amplification now occurs over 100 μs macropulses with 100 A peak current electron bunches produced by a photo-injector. The beam energy is presently limited to 17 MeV so emission occurs around 19 μm with a 3.2 cm period hybrid wiggler. Sidebands have been observed in the FEL radiation spectrum.

Wavelengths around 10 μm should be available fairly soon by using a new 1.8 period permanent magnet wiggler.

The actual performances of the FEL will be described along with application to sensivity measurements of new YBaCuO detectors.

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EXPERIMENTAL INVESTIGATIONS OF AN EXTERNAL FEEDBACK SYSTEM FOR WAVELENGTH SELECTION OF HIGH-POWER MICROWAVE RADIATION IN A FREE–ELECTRON MASER REGIME.

V.A.Bogachenkov, V.A.Papadichev, I.V.Sinilschikova, O.A.Smith
P.N.Lebedev Physical Institute, Leninsky Prospect 53,
117924 Moscow, Russia

Results of experiments to produce high-power microwave radiation by using a selective external feedback system are presented. The generator has a helical undulator and operates in a free-electron maser regime (FEM) with an electron energy of up to 1 MeV and total beam current of up to 1 kA.

Selective feedback is achieved by reflection of radiation of given wavelength back to the FEM chamber from echelettes operating in an autocollimation regime. The amplitude and frequency responses of tuned systems at 55 GHz and 70 GHz were measured with a sweep generator. Echelettes were located externally to the FEM chamber and the aperture of the radiation beam was matched to the transverse dimensions of an echelette by means of a teflon objective.

The magnitude of the extracted power was sufficiently large to cause microwave breakdown, which was observed at the output aperture of the 10 cm diameter radiating horn. For 70 GHz tuning, the radiation power density based on the field intensity of microwave breakdown in the plane of the aperture was estimated to be ≈ 2 MW/cm^2. Considered also are the advantages of this system for obtaining a narrower spectral line of radiation in the millimeter and submillimeter wavebands.

Th3–19

OPTICAL MODE ANALYSIS ON THE CLIO INFRARED F.E.L.

R. Prazeres, J.M.Berset, F.Glotin, D.A.Jaroszynski, J.M.Ortega

LURE, bat. 209d, Université de Paris-Sud
91405 Orsay cedex- FRANCE
tel.: 64 46 80 00 fax: 64 46 41 48

The CLIO infrared laser facility presently uses a 8x15mm (2m long) vacuum chamber. The finite transversal dimension of this chamber has an influence on the optical mode and on the cut-off wavelength of the laser. The longest laser wavelength obtainable on CLIO is presently limited to 15μm, which is shorter than that predicted if we considere a pure TEM00 mode.

In order to predict the transverse optical mode of the laser in the optical cavity, a numerical code has been used, which takes into account the transversal gain profile, the diffraction by mirrors and any beam clipping by the vacuum chamber. The application of this code to CLIO shows that high order transversal modes appear because of the limited vacuum chamber dimensions. This is in good agreement with the experimental data showing a bad transmission of the optical line as compared with that predicted for a TEM00 mode, particularly for long wavelengths.

The possibility of increasing the maximum wavelength by using a new undulator with a larger period and a larger vacuum chamber is also discussed.

A MILLIMITER WAVELENGTH FEL DRIVEN BY A PHOTOCATHODE RF LINAC

G.P.LeSage, F.Hartmann, C.Joshi, D.B.McDermott and N.C.Luhmann, Jr

Department of Electrical Engineering, University of California Los Angeles, USA

C.Pellegrini, J.Rosenzweig, and R.S.Zhang

Department of Physics, University of California Los Angeles, USA

R.Bonifacio, L.DeSalvo Souza, P.Pierini

Università di Milano and INFN Sezione di Milano, Via Celoria 16, 20133 Milano - Italy

We present the design of a millimeter wavelength FEL based on the UCLA Photocathode RF linac. The linac energy can be varied between 5 and 20 MeV. The electron pulse duration is 2 ps FWHM, with a peak current exceeding 150 A. The FEL is designed to operate in the High Gain Compton regime controlling the slippage propagating the radiation in a waveguide. The design will permit the exploration of the basic FEL physics in this regime, including the exploration of lethargy, saturation in the steady state and superradiant regime.

Work supported by the USDOE under Grant DE-FGO-90ER-40565 and AFOSR under Grant F49620-92-J-0175 and ARO under Grant Contract DAALO3-91-G-0190

A 1 MW, 130-250 GHz, FREE-ELECTRON MASER FOR FUSION

W.H. Urbanus, C.A.J. van der Geer, A. van der Linden, A.B. Sterk, A.V. Tulupov,
A.G.A. Verhoeven and M.J. van der Wiel
FOM Instituut voor Plasmafysica 'Rijnhuizen', Association EURATOM-FOM,
POB 1207, 3430 BE Nieuwegein, The Netherlands

A.A. Varfolomeev and A.S. Khlebnikov
I.V. Kurchatov Institute for Atomic Energy, Moscow, 123182, Russia

V.L. Bratman and G.G. Denisov
Institute of Applied Physics, 46 Uljanov St., Nizhny Novgorod, 603600, Russia

An update will be given of the construction of the 1 MW, 130-250 GHz Free Electron Maser experiment at the FOM-Institute. The main application of this FEM will be plasma control and diagnostics in future generation magnetic confinement devices. For this application the millimetre wave (mmw) frequency has to be fast tunable over 10% of the centre frequency. Further, a high overall efficiency, > 35%, is required.

The FEM is driven by a 12 A, 2 MeV electron beam. The electron beam line comprises a low emittance, thermionic electron gun, a dc accelerator, the undulator, a dc decelerator and a multi-stage depressed collector. DC acceleration is preferred for fast-tuning of the mmw frequency via the electron beam energy, i.e., via the accelerating voltage. The electron beam line will be completely straight to minimize current losses to less than 20 mA. This is the current to be delivered by the 2 MV dc accelerating voltage power supply. As a result of efficient charge and energy recovery the overall efficiency of the FEM will be over 50%, according to simulations.

The design of the undulator will be presented briefly in this contribution. Extensive information about the undulator will be presented by A.A. Varfolomeev et al. The undulator consists of two sections. The first section (20 cells) has a constant strength, K_{rms}, of 0.52 and the second section (of 14 cells) has a constant strength of 0.42. The first section provides for sufficient linear gain, of 7, for fast start-up. As a result of the tapering an extraction efficiency of 5% is reached. Simulations on gain and efficiency by fully 3-D and time-dependent codes are presented by M. Caplan, and V.L. Bratman et al.

Since a straight electron beam line will be used, the mmw beam has to be moved off-axis to separate it from the electron beam. This separation is done via so-called stepped-waveguides. At both ends outside the undulator the cross section of the rectangular corrugated waveguide increases abruptly from 15×20 mm^2 to ±60×20 mm^2. As a result the mmw beam is split into two off-axis beams. At the position of full separation mirrors are mounted, with a hole in the centre for the electron beam. This way a cavity is formed and the mmw beam is separated from the electron beam. Results of experiments on the stepped waveguides will be presented. Detailed simulations, which take the propagation of the mmw beam in the cavity and the interaction with the electron beam into account, show that 99.8% of the mmw power is in the HE_{11} mode. The mmw cavity is presented more extensively by G.G. Denisov et al.

26Thu

DESIGN AND CONSTRUCTION OF A COMPACT IR FEL*

Ira.S. Lehrman, John R. Sheehan, Jayaram Krishnaswamy,
Ronald.H. Heuer, Michael F. Reusch, Richard Hartley
Grumman Aerospace Corporation
4 Independence Way
Princeton, NJ 08540 USA

We present the design and construction to date of the Grumman Compact IR FEL. This FEL is being constructed as part of a joint research program between Grumman and Princeton University for research in the physical sciences. This device consists of an RF photocathode electron gun, a photocathode illumination laser, an RF S-band source, a beam transport system, wiggler, optical cavity, and beamline diagnostics. The system is designed to produce up to 1400 electron micropulses of 1 – 2 nC at a repetition rate of 10 Hz. The electron beam energy is between 6 – 14 MeV, the micropulse width is 5 – 8 psec, and the expected beam emittance is less than 5 π mm-mrad. The system is designed to lase in the range of 5 – 14 μm with an energy of greater than 100 μJ per micropulse. The RF photocathode gun employs a removable LaB_6 cathode that can be heated to thermionic temperatures for the desorption of impurities and oxides. The illumination laser consists of a diode-pumped ND:YLF mode-locked laser which is amplified by two flash-pumped ND:YLF rods. The output laser beam is frequency tripled to produce 10 μJ of 349 nm radiation. The S-band source is designed to produce up to 30 MW of power at 2856 MHz for 10 μsec. A feed-forward correction system will be employed to flatten the RF phase and amplitude during the pulse. The beam transport system consists of low-cost electromagnetic quadrupole, dipole and steering correction magnets. A number of wiggler options will be considered. For initial operation, a 1 cm period permanent magnet wiggler will be used. Later, superconducting or pulse electromagnetic wigglers will be used. Beamline diagnostics will include phosphor screens, Faraday cups, and toroids.

*Work supported by the Grumman Corporation.

Submitted By: Ira S. Lehrman
Signed: Ira S. Lehrman
Institute: Grumman Aerospace Corporation
Telephone: 609-520-1808
Fax: 609-520-1810
email: LEHRMAN@GRUMP.COM

THE PARAMETRIIC FREE-ELECTRON LASER IN SUBMILLIMETER WAVE-LENGTH REGION

V. I. Alexeev, K. A. Belovintsev, E. G. Bessonov,
A. V. Koltsov and A. V. Serov.
P. N. Lebedev Physical Institute Russia Academy of Sciences, Leninsky Prospect 53, Moscow, Russia.

The new experimental facility has been developed for generation, research and application coherent undulator radiation in submillimeter wave-length range. It used experience that obtained early at construction of the parametmetric free-electron laser in millimeter wave-length range [1].

The source of relativities electrons is the microtron on the energy of 7 MeV. After extraction from the microtron the electron beam passes through a beam transport line and is focused on to the entrance of the linear hybrid-type magnetic undulator [2]. The rectangular waveguide resonator with the low-loss cylindrical mirrors is used [3]. The undulate radiation is registered by the detector based on InSb crystal. The detector is placed in the helium cryostat. The placing InSb crystal inside the superconducting solenoid allows to shift the sensibility of the detector to the shoter wavelength region. The first experimental results are presented and discussed.

[1] V. I. Alexeev, E. V. Alieva, K. A. Belovintsev, E. G. Bessonov, A. V. Serov and P. A. Cherenkov, Nucl. Instr. and Meth., A 282, 436 -438 (1989).
[2] V. I. Alexeev, K. A. Belovintsev, E. G. Bessonov, A. V. Serov. Kratkie Soobsch. Po Physike N4, (1984) 303 (translated by Allen Press, Inc: Sov. Physics-Lebedev Inst. Reports).
[3] L. R. Elias and J. C. Gallardo, Appl. Phys. B 31, 229-233 (1983).

CARMS AT THE MILLIMETER AND SUBMILLIMETER WAVELENGTHS

V.L.Bratman

Institute of Applied Physics, Russian Academy of Science,
46 Ulyanov Str., 603600 N.Novgorod, Russia

In spite of very favourable predictions of the theory, cyclotron autoresonance masers (CARMs) with high Doppler frequency up-conversion [1,2] are investigated less essentially than ubitrons. Meanwhile, at the wavelengths from 10 mm to 0.1 mm electron energies required for CARMs are many times smaller, since it is easier to obtain short periods of the Larmor trajectory in a strong magnetic field than in a spatially-periodical undulator field. Up to now, both theoretical and experimental investigations have not given any indications on insurmountable difficulties for CARMs or decisive advantages for ubitrons in the above wavelength range. Moreover, the same electron optics and electrodynamical systems are often suitable for both varieties of FEMs (but, of course, they differ in pumping oscillations systems).

Single mode CARM generators and amplifiers with operating wavelengths from 8 mm to 2 mm with output power up to 50 MW and efficiency up to 10% have been realized by collaborators of the IAP together with our colleagues from the HCEI (Tomsk) and JINR (Dubna). Results of the last experiments as well as ways to enlarge the electron efficiency will be discussed in the report. Besides, new projects of CARMs for ECRH (2 MW at 1 mm, cw) and diagnostics (1 MW at 0.2 mm, 10 μs) of fusion plasma, which are now being developed in the IAP, will be described.

1. Bratman V.L., Ginzburg N.S., Petelin M.I. Optics Communications, 1979, Vol.30, pp.409-412.
2. Bratman V.L. and Denisov G.G. International Journal of Electronics, 1992, Vol.72, pp. 969-981.

Application of a 3D Time Dependent Code for Predicting the Spectral Purity and Stability of the 1MW 200 GHz FOM FEM Oscillator

Malcolm Caplan
Lawrence Livermore National Laboratory
P. O. Box 808, L-637
Livermore, CA 94551
U.S.A.

A Free Electron Maser is being developed at the FOM Institute Holland capable of producing 1MW CW output in the range of 200 GHz. The design was obtained using a steady state (single frequency) 3D non-wiggle averaged beam waveguide interaction code including AC space charge effects.* In order to determine spectral purity and verify single frequency constant output, a time dependent version of this code simulating many interacting buckets has been developed which follows the build-up of the original multi-frequency signal from noise allowing for excitation of sidebands and chaotic non-steady output. The integrity of the existing FEM design is verified while conditions that result in multi-frequency low performance output are identified.

*Caplan et al, 14th International Free Electron Laser Conference, Kobe, Japan.

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-8.

ANALYTICAL DERIVATION OF OK AND FEL 3-D GAIN FOR FINITE EMITTANCE AND ENERGY SPREAD ELECTRON BEAM

V.N.Litvinenko

FEL Laboratory, Box 90319, Duke University ,Durham, NC 27708-0319, USA
Telephone: (919)-660-2658; Fax: (919)-660-2671, e-mail: vl@phy.duke.edu

Abstract

The elegant approach for rigorous analytical derivation of 3-D gain for an optical klystron (OK) and a conventional FEL with finite emittance and energy spread electron beam is presented. The following condition are assumed:

a) The electron beam has an arbitrary Gaussian distribution in 3-D phase space.
b) A Gaussian TEM_{00} transverse optical mode in the optical cavity.
c) FEL in small signal, low gain regime.

The gain is expressed as the product of a filling factor and gain for an ideal (zero emittance and zero energy spread) electron beam. The filling factor is given in the form of an integral along the FEL of a slowly varying function.

The dependence of the gain on Rayleigh range and electron beam β-functions is studied as a function of electron beam emittance. The conditions for optimal gain are described. A simple approximate formula for the gain in these conditions is presented with a comparison to rigorous analytical results and computer simulation.

An extension of this approach for higher optical modes (TEM_{nm}) is considered.

3–D SIMULATIONS OF FEL OSCILLATOR

Zili Weng and Yijin Shi

Institute of Atomic Energy of China

P.O.Box 275(18),Beijing,102413

Abstract: A code for simulation of 3–D FEL oscillator has been developed on PC–386, which is totally the same as FELEX of Los Alamos in physical and mathematical formulation with the same accuracy but takes much less amount of calculation, at least, less in one or two orders because of the improvement in numerical algorithms. Using this code, several calculations were done as follows: 1. In single mode cases, (a)the variation of FEL saturated power caused by non–ideal injection, change in emittance and energy spread of e–beam in a certain region are not considerable, moreover, it becomes weakened when output coupler is small. Specially in the case of output coupler 2%, the saturated power of non–ideal injection exceed that of ideal injection a little. (b)the influences of non–ideal injection on optical beam quality are not serious, they also become weakened when output coupler is small. 2. In multimode(16) cases, the calculations show that side–bands can not grow up when output coupler is large, and non–ideal injection, emittance can slow down the growth of side–bands.

Keywords: FEL oscillator 3D simulation, non–ideal injection, side–band

26Thu

THREE-DIMENSIONAL SIMULATION OF LITTROW-GRATING SIDEBAND SUPPRESSION IN A 10 KW FREE-ELECTRON LASER

David C. Quimby
STI Optronics, Incorporated
2755 Northup Way
Bellevue, Washington 98004 USA

and

Claudio G. Parazzoli
Boeing Defense and Space Group
Seattle, Washington 98124 USA

Abstract

The Average Power Laser Experiment (APLE) is a 10 kW free-electron laser (FEL) oscillator operating at 10 μm. Sideband control is required for optimal tapered-undulator power extraction. The results of numerical simulations of the performance of various sideband suppression techniques are presented.

The 1-D code FELP predicts an optical power loss of about 50% with the onset of sideband development. One-dimensional simulations predict that cavity-length detuning will be ineffective in restoring full extraction for the relatively long micropulses (60 ps) and large output coupling (25%) of APLE.

Sideband suppression with a 10 lines/mm Littrow grating on one of the cavity end mirrors is examined using a full three-dimensional, time-dependent numerical simulation with the FELEX code. This simulation includes all relevant physical effects including optical pulse stretching, angular wavelength dispersion, and apertures in the resonator. The time structure of the optical micropulse is sampled using 100 wave fronts and the axial structure of the electron beam current is based on a PARMELA simulation of the APLE beam line. Addition of the grating restores near-ideal power output. The calculated power spectrum is near Fourier transform limited with a FWHM of 0.07%, in good agreement with analytical predictions. The resulting resonator efficiency (optical extraction/electron extraction) is found to be about 80%. The predominant optical losses are scattering from the grating (4%) and diffraction losses at apertures (2%). Littrow grating operation increases the sensitivity of the FEL to changes in e-beam energy, thus establishing an important tolerance for the allowable energy fluctuation level.

ANALYSIS AND OPTIMAL DESIGN STUDY OF TAPERED FEL AMPLIFIERS ON THE BORDERS OF RAMAN AND COMPTON REGIMES

S. Kawasaki and M. Takahasi
Saitama Univ. Faculty of Sci. 255 Shimo-ohkubo, Urawa 338 JAPAN,
H. Ishizuka
Fukuoka Inst. of Tech. Wajiro, Higashiku, Fukuoka 811-02 JAPAN
and
K. Sakamoto, Y. Kishimoto, S. Musyoki, A. Watanabe, and M. Shiho
Department of Fusion Engineering Research, Japan Atomic Energy Research Institute, Nakamachi, Ibaraki 311-01 JAPAN

Detailed processes of FEL activity in a planar wiggler were studied with a 3D non-linear simulation code. The parameters of the particles and the device are chosen in accordance with the experiment carried out at JAERI using a pulsed intense electron beam of mildly relativistic energy(1 MeV, 2 kA and 200 ns)[1]. The evolution of the beam and the resulted radiation were analysed mostly in the multi-dimensional parameter spaces; a lot of tapering patterns are examined for various field gradients, starting points of the tapering, particle intensities and energies, strength of subsidiary axial field for focusing, etc. Optimal design of the tapering style to supply with the maximum FEL power was determined in compromise with the available wiggler field. It is concluded that the final conversion efficiency of the beam energy with the optimal tapering depends considerably on the wiggler parameter K. A large enhancement of the output radiation might not be expected in the present JAERI experiment even with the optimal design. Special attention was payed for the discrimination of the working regimes of Raman and Compton, considering the effects of space charge and of the finite beam energy spread, which was newly measured directly. An analytical theory discussed to give a physical insight for the behaviour of the particles radiating in the tapering wigglers. The simulation was also extended to the case where a higher power beam would be used to produce the radiation of GW level, in view of the future scaled-up model of the device(2 MeV, 5 kA and 150 ns) and its application to Tokamak plasma control.

1)M. Shiho et al."Millimeter wave amplification with a focusing wiggler":Proc. of 14th Intern. FEL Conf., Kobe, 1992. To be published in Nucl. Instr. Meth.

ON THE PLASMA BASED FELS

V.A.Bazylev

Scientific Research Center "Soliton - NTT",

Kurchatov Institute of Atomic Energy, Moscow 123182, Russia

T.J.Schep, A.V.Tulupov

FOM-Institute for Plasmaphysics "Rijnhuizen", Postbus 1207,

3430 BE Nieuwegein, The Netherlands

Different possibilities of creation of compact FELs with plasma undulators that generate radiation in the wavelength range from mm up to X-ray are considered. Two radiation mechanisms can be used.

1.Coherent transition radiation based on the deep modulation of the plasma electron density. A number of structures can be considered as a short wavelength radiator: standing Langmuir solitons or collapsing caverns, fast nonlinear longitudinal plasma waves, artificial periodical structures (foils) that are converted to the plasma state by a powerful current generator and periodical z-pinches produced from a thin wire.

2.Undulator radiation based on transverse oscillations of electrons in an ion-ripple or plasma structures with an ion-channel which is beam-produced.

SPACE-CHARGE MODELS IN RAMAN FEL SIMULATIONS

Ge Zhang and Jonathan S. Wurtele

Department of Physics and Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge MA 02139

Recent studies of a free-electron laser (FEL) microwave amplifier show that the predicted efficiency is quite sensitive to the details of the space-charge model. Of importance are the number of harmonics used in calculating the space-charge force and the method of including finite radial effects and the waveguide wall. The results of the different models will be compared to each other and benchmarked against experimental data. An understanding of space-charge forces in the Raman regime is essential if simulation codes are to be used in the design of high efficiency sources.

CHERENKOV GENERATION OF RAYLEIGH ELECTROMAGNETIC WAVE IN GYROTROPIC PLASMA WAVEGUIDE

IVANOV S. T. AND ALEXOV E. G.

FACULTY OF PHYSICS, SOFIA UNIVERSITY
5 J. BOURCHIER BLVD., SOFIA 1126, BULGARIA

The area of relativistic plasma microwave electronics has only recently generated renewed interest [1]. Both the theoretical and the experimental investigations of the plasma generators have been conducted for nonmagnetized plasma (isotropic medium) or absolutely magnetized (infinitely external magnetic field $B_0 \Rightarrow \infty$) plasma (a single axis anisotropic medium).

The final magnetic field B_0 essentially changes the physics of the problem - in the bounded structures with a gyrotropic plasma the eigenmodes are Rayleigh electromagnetic waves [2,3], which properties and characteristics qualitatively differ from these of isotropic and single-axis anisotropic plasma [4,5].

We suggest a Cherenkov generator in which the Generalized Rayleigh Surface Wave (GRSW) in magnitoactive plasma waveguide is excited by a relativistic electron beam. The GRSW has a phase velocity closed to the velocity of light, which facilitates its radiation. In such a wave the E_z-field and P_z-power flux are spatially separated. This leads to the separation of the effective interaction volume from the space of the power flux maximum, which reduces the inverse action of the wave generated by the beam on the latter. In this way a substantial rise in the efficiency and the stability of the generation is ensured.

For gyrotropic plasma the Maxwell equations have been used, while the beam electron motion has been described by the equation of relativistic hydrodynamics. We solve analytically the problem of an excitation of a GRSW in the complex zone (the area in ω, k_z-plane with complex transverse wave constants) in a gyrotropic plasma waveguide. The growth rate, the dependence of the phase velocity on frequency and of the frequency on the beam energy has been found. The estimation of the nonlinear saturation of the excited wave amplitude, which is defined by the beam particles capture in the wave field has been obtained.

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26Thu

CHAOS IN FREE-ELECTRON LASERS†

Chiping Chen
Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139, USA

This paper reports the results of recent theoretical and experimental research on chaos in free-electron lasers. Topics to be discussed range from single-particle Hamiltonian chaos[1,2] in electron beam transport through a wiggler to many-body chaotic phenomena, such as the appearance of irregular optical spikes, in the self-consistent FEL interaction. The emphasis is on the intimate connection between theory and experiment in these exciting research areas.

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† Research supported by the U.S. Department of Energy High Energy Physics Division.

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1-D Simulation of a waveguide Free-Electron Laser using Bragg Reflectors[A]

Sun Kook Kim, Byung Cheol Lee, Sung Oh Cho*,
Young Uk Jeong, Byung Ho Choi, and Jong Min Lee

Atomic Spectroscopy Department, Korea Atomic Energy Research Institute, P. O. Box 7, Taedok Science Town, Taejon, 305-606, Korea

**Nuclear Engeering Department, Seoul National University, San 56-1, Shinrim-dong, Kwanak-ku, Seoul, Korea*

Small-signal gain and oscillation process have been investigated in a millimeter-wave free-electron laser whose cavity is composed of a waveguide and two Bragg reflectors. The 1-D simulation code includes coupling of the electron beam with various transverse modes. The parameters used in the simulation are those of the KAERI FEL [1,2]. It is shown that the reflectivity of the Bragg reflector depends very much on the depth of the gratings. It is possible to select a single transverse mode by using Bragg reflectors. Start-up time of the oscillator is 2 μs, and the expected output power is above 1 kW.

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EXPERIMENTS WITH UNDULATOR RADIATION OF A SINGLE ELECTRON

I.V. Pinayev, V.M. Popik, T.V. Shaftan,
A.S. Sokolov, N.A. Vinokurov, P.V. Vorobyov
Budker Institute of Nuclear Physics
11 Lavrentyev Ave., Novosibirsk, 630090, Russia
Tel: 7-(3832)-359977 Fax: 7-(3832)-352163
E-mail: pinayev@inp.nsk.su

Abstract

A single electron circulating in storage ring is a very peculiar object. Its unique feature is a permanent emission of synchrotron radiation leading to possibility of observation of the electron but also causing "natural bunch length". In the quasiclassical treatment electron position uncertainties results from the averaging of energy and position of the point-type electron over many turns in the storage ring. More accurate consideration leads to a question about the electron localization. The radiation from long undulator permits to obtain "snapshots" of the electron longitudinal distribution. The experiments with single electron on VEPP-3 optical klystron are discussed.

MICROWAVE TRANSPORT IN THE ION-CHANNEL GUIDED FREE-ELECTRON LASER

K. Takayama[1], J. Kishiro[1], T. Ozaki[1], K. Ebihara[1], T. Kikunaga[2], H. Katoh[3]

1 National Laboratory for High Energy Physics in Japan (KEK)
Tsukuba, Ibaraki, 305 Japan
2 Central Research Laboratory, Mitsubishi Electric Corp.
8-1-1Tsukaguchi, Amagasaki, 661 Japan
3 Dynamic Numerical Simulation Inc.(DYNAS)
2-17-2 Sihnyokohama, Kohoku, Kanagawa, 222 Japan

Abstract

The KEK ion-channel guided X-band free-electron laser(IXFEL) has achieved the output peak power of 40MW with beam current of 400A and beam energy of 1.5MeV(kinetic). To our knowledge, the X-band free-electron laser is a device with longest wavelength in the existing FELs, which is rather a fast-microwave amplifier (or travelling wave amplifier) than a FEL in a narrow sense. Smooth or loss-less microwave transmission is essential in such a device because the device has been originally developed as a possible power source of future linear colliders.

The IXFEL consists of static RF components; RF 90 degree input bend which is connected to the ceramic window following the tapered waveguide with the 100kW magnetron at the end, straight oversized rectangular waveguide corresponding to the amplifier region, laser window with dual functions of vacuum shielding and reflection-less laser beam transfer, and large horn antenna emitting the microwaves into the anechoic room. In addition to these static components, the amplifier waveguide is fill with a thin plasma employed for driving beam guiding. The plasma layer is known to serve as a dynamic (active) medium in microwave transmission. The IXFEL has so far indicated various undesired features in microwave transmission originated from the active medium and unoptimized static devices, such as large shot-to-shot jitter, large reflection, and higher mode conversion.

For the purpose to understand those features of microwave transmission seen in the IXFEL, we have done a systematic study on reflection and mode conversion at each of static devices by experimental, analytical (modal analysis), and simulational(MAFIA simulation) approaches; further, we have developed a theory to explain novel aspects related to the active medium. It is emphasized that through a series of study a fully analytic theory for RF window and a mode conversion theory based on the coupled wave theory, which will serve as a useful tool for future design, have been developed. At the Conference, most of results will be reported and the status of improvement in the IXFEL relied on these studies will be mentioned.

Th3–55

HARD X-RAY PRODUCTION IN A VISIBLE-WAVELENGTH FREE-ELECTRON LASER

Juan C. Gallardo

Physics Department

Brookhaven National Laboratory

Upton, New York 11973 USA

Abstract

Coherent beam of X-ray photons (90 KeV) will be produced by Compton backscattering of visible free-electron laser photons by the same bunched electron beam that maintain 0.2-0.4 GW intracavity power in the stable almost concentric resonator. This process is a natural consequence of the micropulse separation $\tau = 12.5\,\mathrm{ns}$ which corresponds to a situation where two photon pulses are simultaneously in the optical cavity. The interaction occurs at the center of the resonator between the $\approx 6\,\mathrm{ps}$ electron pulse and the returning photon pulse.

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STABLE-UNSTABLE FREE ELECTRON LASER RESONATORS

Chun-Ching Shih
TRW, MS O1/1210, One Space Park
Redondo Beach, CA 90278 USA

There are very few widely tunable coherent sources in the mid to far infrared region where many interesting applications can be found in photo-chemistry, surface physics, and semiconductor materials. Free electron lasers designed at these wavelengths proved to be very attractive for such applications because (1) the devices are relatively compact and less costly compared to the ones designed in the visible or ultra-violet region; (2) the devices provide high-power pico-second pulses with transform-limited properties; and (3) the devices are convenient for tuning over a wide range of wavelength. However, the wide-range tunability in the far infrared region excludes the use of dielectric-coating mirrors and transmissive optics. Recently, a special stable-unstable resonator configuration has been proposed to facilitate this requiremment.[1-2] The device has a stable resonator property in one dimension to support gaussian modes and a one-sided confocal negative-branch unstable geometry in the other dimension. This resonator can be designed using toroidal mirrors to provide different radii of curvature in transverse directions. The negative-branch configuration is necessary because it provides a focal region for the radiation and e-beam interaction and also the possibility of one-sided outcoupling. The numerical analysis using Fox-Li type calculations has shown that this resonator can support the lowest-order mode from 3 µm to 25 µm with a satisfactory beam profile in the interaction region. However, for a magnification of 1.1, the outcoupled beam is in the low-intensity and poor-quality region of the mode. This problem can be alleviated by moving the outcoupling scraper from the small mirror location to the focal position, thus creating a self-imaging stable-unstable resonator.[3] Sharp edges of the scraper usually create undesirable intensity variation in the far field, thus reducing the beam quality. In this paper, we propose to use a two-sided outcoupling stable-unstable resonator configuration with a simple one-dimensional beam compactor. The two outcoupled beams can be combined to form a beam having an approximately gaussian profile. The results of mode analysis and far field evaluation will be presented.

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26Thu

ADVANCED HYBRID UNDULATOR SCHEMES PROVIDING ENHANCED TRANSVERSE E-BEAM FOCUSING

A.A.Varfolomeev, A.H.Hairetdinov
Coherent Radiation Laboratory, Russian Research Center
'Kurchatov Institute', Moscow 123182, Russia

Abstract

New hybrid permanent magnet undulator schemes were analysed. The goal was to find magnet configuration which can provide transverse profiles of the magnetic fields sufficient for electron beam focusing in both transverse directions along with strong undulator magnetic fields comparable with the limit obtainable with the usual hybrid type undulators. Schemes with side magnet arrays, satellite magnets, pole tips with holes and asymmetrical additional magnets sets were considered. Numerical simulations with 2D code PANDIRA and 3D code TOSCA were completed. It is shown that an effective e.b. focusing field profile of the undulator can be achieved with side arrays of permanent magnet cells. Undulator pole tips can be plane in this case which give higher magnetic fields than shaped poles provide. Depending on the position and the size of the additional magnet blocks the focusing can be very effective up to equal ones in both transverse directions. Actual 3D magnetic field maps are obtained from the simulations with using the non-linear iron magnetisation curve and coercitive force and residual magnetisation of Sm_2Co_{17} permanent magnets.

For the undulator with 40 mm period, 25 mm gap and 15x15x30 mm^3 side magnet blocks the maximum transverse magnetic field B_w is equal to 2.2 kGs, and the relative focusing strength is equal to 3.45. The obtained results prove the KIAE-4 undulator construction designed for FOM-FEM project [1].

Another more complex undulator magnet configuration was found which enables strong enhancement of the undulator field and the transverse focusing as well. The configuration resembles a hybrid scheme where the iron poles are covered by permanent magnets from all sides except gap, constituting full 3D geometry of the hybrid undulator. For this case the field strength can exceed up to 30% the classical 1D hybrid scheme limit.

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26Thu

HELICAL UNDULATOR FOR FAR INFRARED FREE ELECTRON LASER

A.I.Bukin, E.B.Gaskevich, V.G.Kurakin and O.V.Savushkin

Department of High Energy Physics, Lebedev Physical Institute Leninsky Prospect 53, 117924 Moscow, Russia

The results of experimental study of pulsed helical undulator for far infrared free electron laser (FIRFEL) being currently under putting into operation are discussed. The undulator parameters had been chosen to rich laser saturation during accelerator current pulse (6 -8 μs), Lebedev Physical Institute Racetrac Microtron being used as laser driver. Undulator double-started winding which consists of 35 periods with 3.2 cm spacing between them had been made from copper wire with diameter of 2.5 mm. Matching of helical trajectory inside undulator with rectilinear one outside is provided by means of rapid field drop with appropriate low at undulator ends. Such non adiabatic undulator entries give one more possibility to shorten resonator length and thus to decrease diffraction losses of laser beam mode. The maximum value of magnetic field on the undulator axis is equal to 3.5 kGs. The simple method of field correction with the help of induced currents in special form copper plate is proposed. The method of detecting of short pulses of undulator radiation by means of optical-acoustic converter, which had been investigated in experiments on accelerator is described.

Investigation of Raman Free-Electron Lasers with a Novel Bifilar Helical Small-Period Wiggler

Bibo Feng, Mingchang Wang, Zhijiang Wang
Zaitong Lu and Lifen Zhang

Shanghai Institute of Optics and Fine Mechanics,
Academia Sinica,
P.O. Box 800-216,
Shanghai 201800, P.R. CHINA
Tel: +86-21-9534890 ext.535, Fax: +86-21-9528885

ABSTRACT

A Raman free-electron laser with a novel bifilar helical small-period wiggler is presented. The magnetic characteristics of such a wiggle are measured, and the maximum transverse field of the wiggler as high as 1500 G has been obtained with the wiggler period 10 mm and gap 15 mm. The experimental results indicated that the free-electron laser operates in the range of 3 millimeters when using a limited pulse duration of electron beam (300 keV / 400 A, 60 ns), and the maximum laser power of 600 kW is observed, corresponding to electron efficiency of 0.5 %.

OPERATION OF THE CLIO INFRARED LASER FACILITY

J. M. Ortega,

LURE, bat. 209d, Univ. Paris-Sud, Orsay, 91405 - FRANCE

ABSTRACT :

The RF linac based CLIO FEL has lased for the first time in January 1992 and has been used progressively as an user facility since approximately mid-92. Its spectral range is 2.5 to 15.5 μm and the peak power is several MW in 1 to 10 ps pulses(1). The average power is adjustable up to a few Watts by varying the repetition rate. The maximum wavelength is presently limited by the diffraction on the vacuum chamber but will be extended in the near future.

The main difficulty of the facility has been to share a single beam time between the various users needs : accelerator maintenance and optimization, FEL optimization and development, FEL physics and, last but not least, users experiments. Nevertheless we are now offering approximately 1000 hours/year of effective laser beam time to users. This amount will increase in the years to come.

We summarise the first user experiments and requirements in the following fields :

- Semiconductors physics
- Surfaces and interfaces (Electro-Chemistry) studies by SFG ("sum frequency generation")
- Near field infrared microscopy
- Vibrationnal energy transfers in molecules in rare gas matrices.

The beam time is allocated by an independent programme committee refereeing the projects submitted by the users. The demands exceed the available beam time largely (by a factor 3 this year).

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26Thu

HIGH FREQUENCY PHOTOCATHODE RF GUN PERFORMANCE

S.C. Chen, J. Gonichon, C.L. Lin, S. Trotz, B.G. Danly, R.J. Temkin
and J.S. Wurtele

Plasma Fusion Center and Department of Physics
Massachusetts Institute of Technology
Cambridge, MA 02139

A 17 GHz RF gun experiment is being constructed at MIT. The goal is to study particle acceleration at high field gradients and to generate high quality electron beams for potential applications in next generation linear colliders and free electron lasers. The RF gun has a 1 1/2 cell cavity with a design peak accelerating gradient of about 250 MV/m. The anticipated beam parameters, when operating with a photoemission cathode are: energy 2 MeV, normalized emittance 0.43π mm-mrad, energy spread 0.18%, bunch charge 0.1nC, and bunch length 0.39 ps. Field emission phenomena at 17 GHz under high gradients will be studied in the experiment. This paper will describe the experimental setup, including the high frequency cavity, the RF transport line, and the picosecond UV laser system, and give a summary of related theoretical progress, including an equivalent circuit model for the coupling into the gun and frequency scaling relations for beam quality in RF guns.

Power and Efficiency Optimization of the Compact CREOL FEL

Luis R. Elias, Isidoro Kimel, Kent Hopkins, Mufit Tecimer and Paul Tesch

Center for Research in Electro-Optics and Lasers (CREOL) ..nd Department of Physics, University of Central Florida, Orlando, FL 32826

ABSTRACT

An important feature of the compact CREOL FEL[1] is that it will operate efficiently as a CW, high-average power laser source. It's expected performance stems chiefly from the nearly complete charge and energy recovery capability of properly modified electrostatic accelerators.

In this paper we present numerical studies dealing with laser power optimization and beam recovery efficiency of the compact CREOL FEL. The studies used a one dimensional numerical code designed to analyze the time evolution of long pulse FELs operating in either an amplifier or in a resonator configuration. For the design parameters of the compact CREOL FEL it appears that maximum output power occurs when the output coupler is set for 10 % transmission. Reducing the small signal gain by a factor of four decreases the optimum coupler transmission to 3%.

Phase space studies of the spent electron beam indicate that a four-stage electron collector will recover the spent electron beam (V= 1.7 MV, I=0.2 A) with joule heat losses of 500 W. Since the laser power is 630 W, the laser efficiency will be better than 55%. It power supply and generator losses are included, the overall (i.e., wall-power) laser efficiency can be as high as 30%. Increasing the beam current to 300 mA will increase the average output power to more than 1 kilowatt.

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26Thu

DESIGN OF A BY-PASS LINE FOR AN UNDULATOR FOR THE STORAGE RING EUTERPE

M. VENIER (*)(#), BOLING XI (#), J.I.M. BOTMAN (#), M. CONTE (*)
(*) Physics Dep. of the University of Genoa /
I.N.F.N. Genoa
Via Dodecaneso 33
I-16146 Genova
(#) Cyclotron Laboratory
Eindhoven University of Technology
P.B. 513
NL-5600 MB Eindhoven

ABSTRACT

This project consists of designing a by-pass line to be added to the storage ring EUTERPE, the new facility being built in the Cyclotron Laboratory at the Eindhoven University of Technology.

The aim of by-pass is to have a transfer line for a FEL system where coherent radiation in the XUV region will be produced.

The by-pass should match the lattice function of EUTERPE with the optical functions of the insertion device used for the FEL. The beam line should be very flexible in order to accomodate different insertion devices, such as undulators, optical klystrons or others, without modifying the whole set-up.

In this paper various structures will be considered in two different situations: a short by-pass inside the circumference of EUTERPE and a longer one outside.

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TRANSPORT OF RF-PHOTOCATHODE GUN PRODUCED BEAM WITH CONTAINED EMITTANCE GROWTH

Juan Gallardo, Harold Kirk and Xiaohao Zhang

Physics Department and NSLS

Brookhaven National Laboratory

Upton, New York 11973

(May 10, 1993)

Abstract

We discuss possible designs of collinear RF-photocathode gun and linac sections as injectors to FEL experiments. An inverse-Helmholtz solenoid pair is used to control the divergence of the electron beam and present a slightly convergent and small radius beam into the linac. Furthermore, the drift from the gun to the entrance of the accelerator and the strength of the solenoid are chosen to allow the space-charge forces to self-correct the growth of the transverse emittance. Solutions for 1 to 2.5 nC will be presented. The simulation code PARMELA is used to model the beam through the transport system.

INFRARED FEL PHOTOCHEMISTRY: MULTIPLE - PHOTON DISSOCIATION OF FREON GAS

Brian E. Newnam, James W. Early, and John L. Lyman
Los Alamos National Laboratory
Chemical and Laser Sciences Division, MS J564
Los Alamos, New Mexico 87545 USA

Infrared free-electron laser (FEL) radiation has several characteristics that should make it useful for practical photochemistry. These include broad tunability, adjustable spectral bandwidth, and scalability to high-peak and average power. For more than a decade, FELs have operated over most, if not all, of the infrared spectrum. A feature unique to FELs is synchrotron sideband emission that manifests as a broadening of the lasing spectrum to longer wavelengths during the macropulse. For example, the Los Alamos APEX FEL has operated with up to 10% spectral width within a 100-μs macropulse of 2000 10-ps micropulses. Except for laser isotope separation, which requires bandwidths <0.1 cm^{-1}, the 1-20 cm^{-1} bandwidths corresponding to the 1-20 ps micropulses produced by rf-linac FELs are sufficiently narrow for v arious types of molecular photochemistry.

The man-made chlorofluorocarbons such as Freon 11 ($CFCl_3$) have attracted public attention because they have been linked to depletion of the ozone layer in the Earth's stratosphere. Freons released at the surface of the Earth eventually reach the stratosphere where exposure to sunlight below 200 nm dissociates the chlorine atoms. Each free chlorine atom then catalytically removes an oxygen atom from up to 100,000 ozone molecules.

In the absence of ultraviolet light, Freon gases can be dissociated also by multiple-photon absorption of 30 to 40 infrared photons from a pulsed laser, tuned to the C-Cl or C-F stretch resonances between 8 and 13 μm. Initially, radiation within a specific, narrow-band infrared wavelength is required to excite a molecule up the ladder of discrete energy levels into the quasi-continuum of states. The absorption spectrum of these excited molecules is shifted to wavelengths longer than the initial resonance by up to 10%. Subsequent photons within this broad wavelength range can further excite the molecule past the dissociation level.

We envisioned that the FEL sideband structure could match the broad, excited-state spectral absorption and lead to enhanced dissociation. To test this hypothesis, we tuned the Los Alamos APEX FEL to near the 11.8-μm absorption resonance of Freon 11 and focused the beam through a pair of test cells (1.0 Torr Freon+1.7 Torr air). One cell was exposed to FEL radiation with sidebands; the other without sidebands. Final and initial FTIR absorbance spectra were compared to measure the fraction of molecules dissociated. We describe the results of a small set of exposures.

Work supported by the U. S. Dept. of Defense Strategic Defense Initiative Organization under the auspices of the U.S. Department of Energy.

26Thu

A FEL STUDY OF THE SATURATION INTENSITY OF A DONOR TRANSITION IN Si:P

K.K. Geerinck, J.E. Dijkstra, J.N. Hovenier,
T.O. Klaassen, W.Th. Wenckebach

Faculty of Applied Physics, University of Technology Delft, The Netherlands

A.F.G. van der Meer, P.W. van Amersfoort

FOM-Institute for Plasma Physics 'Rijnhuizen', Nieuwegein, The Netherlands

ABSTRACT

The free electron laser FELIX at the FOM institute Rijnhuizen is used to perform a saturation study of intrasublevel transitions of the shallow donor phosphorus in silicon. The pulse structure of FELIX plays a vital role in these experiments. Normally saturation experiments are performed using a cw or long pulsed light source. Then one can only extract the quantity T_2T_1 from the measurements, where T_1 is the life time of the photoexcited state and T_2^{-1} the homogeneous width of the saturated transition. FELIX, however, allows us the unique possibility to perform the measurements using a long train of pulses with a length $\tau = 12$ ps $\langle\langle\, T_2$. Then the band width of the light from FELIX is much larger than the homogeneous width of the saturated transition and τT_1 extracted from the measurements instead of T_2T_1. Thus we may directly determine T_1 and moreover, by comparison with standard saturation experiments T_2.

We perform our studies on the $1S_0 \rightarrow 2P_0$ transition of a sample of 5 Ωcm Si:P with a thickness of 0.4 mm. The experiments are performed at 18 Kelvin while the magnetic field $\mathbf{B} = \mathbf{0}$. Using the easy tunability of FELIX we scan the transmission of Si:P by tuning across the transition which is observed at 275 cm^{-1}. By performing these scans at different intensities the saturation curves are obtained. From our analysis T_1 appears to be unexpectedly long: of the order of 1 μs.

26Thu

FEL BASED PHOTON COLLIDER AT SLC AS A PROTOTYPE OF FUTURE PHOTON COLLIDERS

E.L. Saldin†, V.P. Sarantsev, E.A. Schneidmiller † and M.V. Yurkov

Joint Institute for Nuclear Research,
P.O. Box 79, Head Post Office, Moscow 101000, Russian Federation
†Automatic Systems Corporation,
Smyshlyaevskoe Shosse 1a, Samara 443050, Russian Federation

ABSTRACT

Physical principles of operation of the high energy photon linear colliders (PLC) based on the Compton backscattering of laser photons on high energy electrons are discussed. The main emphasis is put on the analysis of a possibility of constructing PLC with the center of mass energy $2 \div 10$ GeV at the Stanford Linear Collider (SLC) facility. It is shown that it can be done with minor modifications of the existing facility by installation of new kicker magnets and two-stage free electron laser.

Proposed FEL system consists of tunable FEL oscillator ($\lambda \sim 10 \div 30\mu$m, output power ~ 10 MW) with subsequent amplification of the master signal in a FEL amplifier up to the power $\sim 3 \cdot 10^{11}$ W. The FEL parameters are optimized, restrictions on the electron beam and FEL magnetic system parameters are formulated and the ways of the possible technical realization are discussed.

It is shown that the FEL based photon collider at SLC providing luminosity of colliding $\gamma\gamma$ beams $L_{\gamma\gamma} \sim 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ may be constructed at the present level of accelerating R&D technique. It will be a unique instrument for precision studying of the charmonium and bottomonium physics as well as τ – lepton physics providing $\sim 10^2$ polarized τ – leptons per second. At the same time the Photon Linear Collider at SLC will serve as a reliable test base for constructing of future TeV – range photon linear colliders.

NARROW-BAND OPERATION OF FELIX

D. Oepts, R.J. Bakker, D.A. Jaroszynski, A.F.G. van der Meer,
and P.W. van Amersfoort
FOM-Instituut voor Plasmafysica 'Rijnhuizen', Associatie Euratom-Fom,
P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands

Radiation with a bandwidth on the order of the longitudinal cavity mode spacing, i.e. $\approx 10^{-3}$ cm^{-1} or 25 MHz, has been selected from the output of the Free Electron Laser for Infrared eXperiments, FELIX.

The long wavelength branch of the device was used at λ=41 µm, or ν=243 cm^{-1}, with a relatively large cavity detuning to extend the length of the optical micropulses and to narrow the bandwidth to 1.6 cm^{-1}. An intracavity Fox-Smith interferometer was used to induce coherence bewteen the forty optical pulses that circulate simultaneously through the cavity. As a result of the phase-locking achieved in this way, the laser power was concentrated in modes with a separation of 0.033 cm^{-1} or 1 GHz, corresponding to the electron micropulse repetition frequency.

An external Fabry-Pérot interferometer has subsequently been used to isolate one of the resulting modes from the laser output. The Fabry-Pérot consisted of copper mesh reflectors separated by a 4 mm gap, and showed a finesse of $\approx$30. The transmitted signal has been analyzed with a scanning Michelson interferometer. A continuous fringe signal was observed over the full 240 cm path-difference scan. A bandwidth on the order of 10^{-3} cm^{-1} was deduced from the decay of the visibility of the fringes with increasing path difference.

The power in the resulting radiation has not been measured directly, but it is estimated that an average macropulse power of $\approx$10 W can be obtained. A substantially higher useful power can in principle be extracted by selective outcoupling instead of external selection of one of the modes.

TRAVELLING-WAVE CYCLOTRON (TWC) FREE-ELECTRON MASER

E. Jerby[1] and G. Bekefi[2]

[1]Tel-Aviv University, Faculty of Engineering,
Dept. of Electrical Engineering - Physical Electronics,
Tel-Aviv 69978, Israel

[2]Massachusetts Institute of Technology, Dept. of Physics,
Research Laboratory of Electronics and Plasma Fusion Center,
Cambridge, MA 02139, USA

ABSTRACT

Experiments and theory of a long-wavelength free-electron maser based on an electron cyclotron interaction with travelling waves in periodic waveguide are presented. Two TWC-FEM experiments are described.

In the first experiment done at MIT the TWC-FEM is operated as an amplifier producing over 10 dB gain with low-energy (< 10 *keV*) low-current (< 1*A*) electron beam. In the second experiment performed in Tel-Aviv a similar TWC-FEM is operated as an oscillator. RF power in the order of 100 W was detected in the cavity when a magnetic kicker is activated at the entrance to the interaction region. A theoretical model of the TWC interaction including the periodic waveguide and the initial transverse velocity effects is presented and compared with the experimental results.

3 MM WAVE FREE ELECTRON LASER (FEL) WITH A NEW SMALL PERIOD WIGGLER

Ming Chang Wang, Zaitong Lu, Lifen Zhang
Bibo Feng, and Zhijiang Wang
Shanghai Institute of Optics and Fine Mechanics
Academia Sinica, P.O.Box 800211,Shanghai 201800,China

ABSTRACT

A new small period wiggler configuration constructed by the bifilar helical sheets with ferromagnetic cores for a Raman FEL (300 KeV/400 A) is developed. The performance characteristics of the wiggler with 10 mm period and 600 mm length are measured. A peak field of 1.5 kilogauss for relatively large gap to period ratios, gap/λ_w =1.6, is achieved.

A microwave grating spectronmeter is developed for spectral measurements of Raman FEL diagnostics, two aluminum reflection gratings with groove constants d = 7.5 mm and 3.5 mm, and both with blaze angle $\vartheta = 30^\circ$ are presently used. Stimulated emission is observed at a wavelength near 3 mm from SIOFM FEL with the new wiggler recently. The 15 ns pulse at energy of 9 mJ is measured. Tuning ability of FEL is performed by adjusting the guided field Bo, the mamxium output power appears at Bo = 7500 G.

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Microwave amplifiers and generators of the Cherenkov type with relativistic electron beams produced by field-emission guns

E. Abubakirov, N. Kovalev, N. Zaitsev

Institute of Applied Physics,
603600 Nizhny Novgorod, Russia

The paper discusses possible ways to provide coherence in microwave generators and to enlarge the gain in microwave amplifiers driven by electron beams, which are formed in field-emission (explosion-emission) electron guns and, so, possess a relatively high level of instability (noise). It is shown that in the long-wave part of the millimeter wavelength band, and, especially, in the centimeter wavelength band the most powerful and efficient devices are those of the Cherenkov type (in which electrons moving rectilinearly interact with slow electromagnetic waves). Experimental results for generation of pulsed microwave radiation with powers over 1 GW and amplification of pulse signals to 200 MW are presented. Experiments on mutual phasing of two amplifiers and investigation of mutual coherence of two autogenerators are described.

THE ISRAELI TANDEM ELECTROSTATIC ACCELERATOR FEL-STATUS REPORT

M. Draznin, A. Goldring, A. Gover, Y. Pinhasi, J. Wachtell, Y. Yakover
Dept. of Electrical Engineering - Physical Electronics,
Faculty of Engineering,
Tel-Aviv University, Ramat-Aviv 69978, Israel
Tel: 972-3-36408149

J. Sokolowski
Weizmann Institute of Science, Rehovot, 76100, Israel

B. Mandelbaum, A. Rosenberg, Y. Shiloh
RAFAEL, Haifa, Israel

G. Hazak, L.M. Levine, O. Shahal
N.R.C., Beersheba, Israel

Abstract

Development of the Tandem van de Graaf FEL project was continued. Stabilization of the terminal voltage has been accomplished. Stability achieved ($\Delta E/E$) is ± 0.001.

Some preliminary beam transport measurements were performed. Transport efficiency of 100%(η = 100%) has been measured for low beam currents (up to 170mA) transported through a 3 cm aperture in the terminal. For higher beam currents (550mA) a lower efficiency (η = 60%) was measured. This lower transport efficiency agrees very well with numerical beam envelope calculations. We plan to insert focusing elements (quadrupoles) in the beam line to facilitate beam coupling in and out of the wiggler.

Numerical simulations using SCAT[1] TRACE[2] and TRANSPORT[3] programs indicate that the electron beam can be focused to a radius of about 1.5 mm with beam currents of 1A. Hence we expect to get high transport efficiency with an electron beam of 0.3 A-1A. A prototype of the RF resonator was designed for operation at $\lambda = 3mm$ and is now being built. The resonator waveguide is composed of two curved parallel plates. Preliminary mm-wave transmission measurements indicate that the attenuation of the waveguide is negligible.

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THE PROJECT OF NEW LASER TECHNOLOGICAL CENTER

F.F. BARYSHNIKOV, N.V. CHEBURKIN, V.V. PEREBEYNOS
A.N. SKRINSKY, N.A. VINOKUROV

Moscow Special Design Bureau "Granat" and Budker Institute of Nuclear Physics are planning to establish a new Laser Technological Center in the vicinity of Moscow on the basis of 100 kW race-track continuous microtron recuperator FEL with wavelength range from 1 mkm to 20 mkm. It will be multipurposes and multiusers center for basic research and R&D open for cooperation with organizations in Russia and abroad. If the present level of financial support is preserved, the Center is to be open since 1996.

Prototypes of the most important elements of high power FEL (high frequency generators with feeding system, accelerating RF structures, optomechanical units of FEL, elements of magnetovacuum system) have been developed by present. The main features of RF accelerators and undulators, designed and developed at Budker Institute, are described in the IEEE Journal of Quantum Electronics in the paper devoted to the Novosibirsk International Center for Photochemical Research on the basis of 20 kW FEL.

It is supposed to use the so called method of electron coupling of radiation developed at Budker Institute. The essence of method is in bunching of electron beam in resonator and obtaining high power radiation from bunched electrons in additional undulator beyond the optical resonator. It enables to couple out more radiation power and save the optical resonator from the damage by the powerful radiation within it.

The main purpose of the Center is to promote research program on developing new technologies in different field of physics, chemistry, medicine, biology, space and defence.

The basic financial support is provided for the following fundamental directions: basic and R&D FEL research, laser chemistry, laser processing, isotope separations, space research and defence.

The following problems are under consideration just now: the creation of the photoinjector to guarantee high quality of electron beam; the problem of screening of radiation in long wave limit; the organizations of multiusers' facility for FEL and synchrotron radiation research and electron-beam radiolysis: output of high power radiation: the problem of line width narrowing.

PRESENT STATUS OF THE NIJI-IV FREE-ELECTRON LASER

T. YAMAZAKI, K. YAMADA, S. SUGIYAMA, H. OHGAKI, N. SEI,
T. MIKADO, T. NOGUCHI, M. CHIWAKI, and R. SUZUKI.
Electrotechnical Laboratory,
1-1-4 Umezono, Tsukuba City, Ibaraki 305, Japan
M. KAWAI, M. YOKOYAMA, and S. HAMADA
Kawasaki Heavy Industries Ltd., 1-1 Kawasaki cho,
Akashi, Hyogo 673, Japan

Free electron laser (FEL) experiments are going on with a compact storage ring NIJI-IV dedicated to FEL and a 6.3 m optical klystron. The first lasing at wavelengths between 589 ~ 595 nm has been reported last year. An osciilation at 488 nm was successfully observed on Nov. 18, 1992, which extended the tunable wavelength region over 100 nm.

Preparatory experiments on the FEL around 350 nm with electron beam energy of 313 MeV are being carried out. The FEL gain is estimated to be about 2.2×10^{-3}/mA/bunch with electron beam energy spread of 7.5×10^{-4} which is 1/2.5 of the gain at 595 nm. The round trip loss of the optical cavity is about 500 ppm which is about 6 times as large as that around 595 nm. Those facts suggest that we need the peak electron-beam current of at least 15 times as high as that for lasing around 595 nm. The highest beam current achieved so far is about 6 mA/bunch. However, the overlap of the electron beam and optical beam is very poor because of the flat cross sectional shape of the electron beam. The ring optics and injection system are being modified to obtain higher peak gain.

FEL-Generator and FEL-Amplifier Facility in JINR

A.A.Kaminsky, A.K.Kaminsky, V.P.Sarantsev, S.N.Sedykh, A.P.Sergeev

Particle Physics Laboratory,
Joint Institute for Nuclear Research,
141980 Dubna, Moscow Region, Russia

The description of the experimental set-up for the 8-mm FEL-generator/amplifier investigation with helical undulator and guide magnetic field, is presented.

Some different approaches to undulator design to provide smooth increase and/or decrease of its magnetic field along the axis according to any definte law, are analyzed. The possibility to improve transverse homogeneity of undudlator field, increasing of number of current wires, has been studied with numerical simulation and experimentally. The presented results of the undulator magnetic field measurements have been fulfilled with the help of integral sensors.

The gas-filled calorimeter designed for measurements of energy/power of single microwave pulses is described.

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3D SIMULATIONS OF HIGH POWER FEM OSCILLATOR

A.A.Varfolomeev, M.M.Pitatelev
Coherent Radiation Laboratory, Russian Research Center
'Kurchatov Institute' Moscow 123182, Russia

Abstract

A special 3-D code was written and used for simulation of intense electron beam and e.m. beam interaction in FEM oscillator with closed rectangular cavity of mm-range.

Undulator field Bw was described analytically with one simplification. The entrance and exit cells were not taken into account when the longitudinal electron movement was described. The code admit any section to be tapered. Multisection (up to 5 sections) undulator can be simulated.

The transverse motion of electrons was described analytically. Longitudinal motion was simulated numerically step by steps along z-axis. Space charge effects were included. The transverse structure of the radiation field in the closed cavity was described by a set of eigenmodes of this cavity. The amplitude variations change of each mode were calculated numerically.

The results of the simulations for FOM-FEM oscillator [1] are presented. (Two undulator sections with equal period and different magnetic fields.) The gain and output e.m. power as a function of the electron beam emittance were investigated. It was shown that exit power level more than 1 Mw is possible (60% from the first section and 40% from the second section)

The KAERI FEM project [2] was also examined. The power level of the oscillator can be sufficiently increased if a special two section undulator is used. With e.b. parameters [2] and suggested two section undulator the mm-range radiation power output would reach 40 kW limit.

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A THEORY OF THE BEAM-WAVE INTERACTION FOR A DIELECTRIC CHERENKOV MASER OPERATING IN NON-AXISYMMETRIC MODE

A. S. Shlapakovskii, K. A. Chirko

Microwave Center at the Institute of Nuclear Physics of
Tomsk Polytechnical University, PO Box 25, Tomsk, 634050 Russia

Linear and nonlinear theory have been formulated for Cherenkov interaction between the thin annular relativistic electron beam and arbitrary non-axisymmetric mode of the circular dielectric-lined waveguide. The approach is based on the separation of AC space charge fields and the synchronous wave field. The expressions for the beam-wave coupling coefficient and the AC space charge depression coefficient in the non-axisymmetric case have been derived. Calculations have been carried out in order to compare modes of various azimuthal index including the symmetric TM-mode. Starting currents for oscillator configuration have been determined, and typical geometries have been found where symmetric or nonsymmetric mode dominates or they are of close starting currents.

Nonlinear dynamics of the beam-wave interaction essentially differs from the axisymmetric case. The bunching occurs differently also for a rotating mode and mode with fixed azimuthal structure of field. If neglect the AC space charge fields one can obtain the universal set of nonlinear equations not depending on the number of azimuthal variations. For this case numerical investigations have been carried out.

COHERENCE OF UNDULATOR RADIATION AND ULTRA-RELALATIVISTIC FREE-ELECTRON LASER EFFICIENCY

V.I. Kurilko and V.V. Ognivenko
The Ukrainian Science Center, Kharkov Institute of Physics & Technology, Kharkov 310108, Ukraine

Systematized and generalized are results of a theoretical study on underlying physical mechanisms and quantitatively-derived regularities for production of intense coherent radiation in ultra-shortwave free-electron lasers (FELs). Principal analytic tools used in this study were:

- an analytic descriptive model of motion dynamics of the point electron monoenergetic flux in own undulator radiation field, and
- analytic and computer simulations of functional relationships of bremsstrahlung coherence achieved during the Thomson scattering of a planar electromagnetic wave by charged particle bunches vs. bunch geometries and the number of particles in a bunch.

The performed analytic study allowed to introduce a notion of the minimum wavelength for coherent radiation produced from intense electron beam in the undulator, with the functional relationship established for this wavelength vs. electron volume density in the beam.

COMPUTATIONS OF LONGITUDINAL ELECTRON DYNAMICS IN THE RECIRCULATING CW RF ACCELERATOR-RECUPERATOR OF THE HIGH AVERAGE POWER FEL

A. S. Sokolov and N. A. Vinokurov
FEL Group, Budker Institute of Nuclear Physics
prospekt Lavrentyeva 11, Novosibirsk 90, Russia
Phone: +7(3832)35-9443; Fax: +7(3832)35-2163
Telex: 133116 ATOM SU; E-mail: SOKOLOV@INP.NSK.SU

Abstract

The use of the optimal longitudinal phase-energy motions conditions for the bunched electrons in the recirculating RF accelerator gives the possibility of the FEL gains increase. The computer code RECFEL, developed for simulations of the longitudinal compression of high average currents electron bunch, essentially loading the CW RF linac of the recirculator-recuperator, is briefly described and illustrated by some computations results.

THE NONLINEAR ANALYSIS OF SELF-FIELD EFFECTS IN FREE-ELECTRON LASERS*

H.P. Freund,† R.H. Jackson, and D.E. Pershing††
Naval Research Laboratory, Washington, D.C. 20375
Phone: 202-767-0034; FAX: 202-767-0082

A model of the self-fields associated with the charge density and current of the electron beam is incorporated into 3D nonlinear formulations of the interaction in free-electron lasers for both planar and helical wiggler configurations. The model assumes the existence of a cylindrically symmetric electron beam with a flat-top density profile and a uniform axial velocity, and the self-electric and -magnetic are determined from Poisson's equation and Ampere's Law. Diamagnetic and paramagnetic effects due the electron beam interaction with the wiggler field are neglected; hence, the model breaks down when the wiggler-induced transverse displacement is comparable to the beam radius. The nonlinear formulations are based upon the ARACHNE and WIGGLIN codes which represent slow-time-scale formulations for the evolution of the amplitudes and phases of a multi-mode superposition of vacuum waveguide modes.[1] Electron dynamics are treated using the complete 3D Lorentz force equations, and the representations for the self-fields are incorporated directly into this formulation. The simulations are compared with a planar wiggler experiment at Lawrence Livermore National Laboratory, and helical wiggler experiments at the Massachusetts Institute of Technology and the Naval Research Laboratory. These experiments employed intense electron beams with current densities of 200-1200 A/cm^2 and comparable space-charge depressions of $\Delta\gamma_{self}/\gamma_0 \approx$ 0.53-0.78% across the beam. The simulations are in reasonable agreement with the experiments, and indicate that the self-fields tend to (1) reduce saturation efficiencies and (2) enhance beam spreading depending upon the magnitude of external beam focusing.

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†Permanent Address: Science Applications International Corp., McLean, VA 22102.

††Permanent Address: Mission Research Corp., Newington, VA 22122.

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BEAM TRANSPORT THROUGH TWO SECTION UNDULATOR. COMPUTER SIMULATION RESULTS.

A.A. Varfolomeev, A.V. Smirnov
Coherent Radiation Laboratory, Russian Research Center
"Kurchatov Institute", Moscow 123182, Russia

Electron beam transportation through a two-section planar hybrid undulator is considered numerically. In the electron beam transport problem for two section undulator the most critical point is increasing of the electron beam transverse size in the second undulator section. It caused mainly by the electron beam mismatching at the second section entrance.

The results are obtained with using of 3D particle tracing code UNDYNA which can take into account different kinds of focusing fields with its combinations as well as linearized transverse space charge forces and experimentally measured undulator magnetic field data.

Parameters of the undulator [1] developed for FOM-FEM project were used. The following questions were concerned: how to provide electron beam transport through the undulator with efficiency higher than 99.8% at various electron energy values (1.75 and 2 MeV); how to maintain the synchronism between the electron beam and the radiation field; how to match the electron beam and the magnetic field at the entrance and at the exit of the undulator sections. Both sections of the KIAE-4 undulator [1] have special side magnets arrays which provide transverse magnetic field profiles ensuring the electron beam focusing within any section. It was shown numerically that this periodical magnetic fields induce efficient focusing up to that corresponding to the equal focusing strengths for both transverse directions.

The following options of focusing fields were considered in more details:
i) non equal focusing in both sections, ii) combined focusing (non equal focusing in the first section and close to equal focusing in the second section), iii) pure quadrupole equal focusing in both sections.

The electron beam envelope plots are presented and analysed for these different focusing fields and electron energies. For the option (i) we obtained the best beam confinement in horizontal plane within ± 2.7 mm for both energy values.

The synchronism violence is not serious in all cases. The maximum phase detuning with the 1.2 mm radiation wavelength does not exceed 3.5 degree for the combined focusing option (ii) and 2.0 degrees for the pure quadrupole equal focusing option (iii) respectively. It is shown that KIAE-4 undulator design can ensure the focusing adequate to the project requirements.

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Numerical Investigation of the longitudinal Phasespace of Storage Ring FELs *

A. Geisler
Institute for Acceleratorphysics and Synchrotronradiation
University of Dortmund
P.O. Box 500 500
4600 Dortmund 50, FRG
Fax: (FRG) 231-755-5383
email: andreas@marvin.physik.uni-dortmund.de

The longitudinal phasespace of storage ring based FELs has been investigated by means of the FEL simulation code LOEFFEL. The code is based on a 1-dimensional model of the FEL, i.e. it takes care of the longitudinal effects only. It also models the interaction between the recirculating electrons and the storage ring. Longitudinal phenomena caused by this interaction, e.g. synchrotron oscillations, have some influence on the operation of a storage ring FEL, and can be investigated using the code.

Using this code two FEL devices, both low and high gain, have been investigated and the differences in the evolution of the longitudinal phase space have been worked out. Results of the simulation for LINAC and storage ring operation are presented. In the low gain regime the parameters of FELICITA I are used. This device is currently under construction at the DELTA storage ring of the University of Dortmund and will operate in the wavelength regime between 400–200 nm. For simulation of a high gain device the parameters of FELICITA II are used. This device will be the second FEL at DELTA, working in the wavelength regime about 100 nm and significantly below.

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RADIATIVE INTERACTION OF CHARGES IN PLASMA

Zavtrak S.T.

Institute for Nuclear Problems, Bobruiskaya 11, 220050, Minsk, Republic of Belarus

Recently it was found that the induced oscillation of the small particles under the action of the external fields result in the appearance of the long-range radiative forces [1-3]. These forces are proportional to the square of the field amplitude (for weak fields) and inversely proportional to the distance between the particles (at the far zone). The spacing structure of the radiative forces is one and the same for charged particles and magnetic moments (in electromagnetic wave) [1,2] and for gas bubbles and solid corpuscles (in a sound field) [1]. From the standpoint of the classical theory the radiative forces are caused by the secondary radiative of the particles. The quantum theory of the radiative interaction was constructed in [3] for the example of charges placed in the field of a plane monochromatic electromagnetic wave.

At large distance the radiative forces may predominate over the Coulomb forces. It leads to the principle possibility of forming bound states between even two like charges in plasma (analogous to Cooper pairing). The comparison between the radiative interaction forces and the Coulomb forces gives the value of electric intensity E_o for which these forces are equal, namely $E_0 \simeq mwce^{-1}/\sqrt{kr}$. At wave length $\lambda = 1mu$ and $kr = 2\pi$ for electrons one obtains $E_0 \simeq 1.28 \cdot 10^{10} V/cm$

The long-range radiative forces can be actual for the free-electron-lasers. For example if the current density of electron beam $j = env = 1.8 \cdot 10^4 A/cm^2$ then the characteristic distance between the particles likes to the wavelength the $\lambda = 1mu$.

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COHERENT AND INCOHERENT EVOLUTION IN THE RAMAN FREE-ELECTRON LASER

C Penman*
Faculteit der Technische Natuurkunde
Universiteit Twente
Postbus 217
7500AE Enschede
The Netherlands

Start-up of the free-electron laser is analysed in the Raman régime.

*present address: Dept. of Physics & Applied Physics, University of Strathclyde, Glasgow, UK

Nonlinear Coupling of the Space-Charge and Transverse Magnetic Waves in a High Power Cherenkov Maser

Jeong-Sik Choi

Department of Physics, Dongshin University, Daeho 252, Naju. Chonnam 520-714, Korea

Byoung-Hee Hong and Duk-In Choi

Department of Physics, Korea Advanced Institute of Science and Technology, Taejon 305-701, Korea

Abstract

We analyze the nonlinear saturated state composed of the wave and beam in a dielectric loaded cylindrical waveguide using the cold fluid-Maxwell equations. For the case of strongly magnetized plasma, where the beam may be treated as one dimensional, the most unstable transverse magnetic (TM) mode is dominantly interacting with the relativistic electron beam and grows until it saturates in the final steady state. The nonlinear efficiency of the most unstable wave as well as the real frequency shift is investigated and compared with the results of the numerical simulation. The effects of the beam current, energy, position, and the dielectric materials on the efficiency are discussed. It is shown that the amplication of the electromagnetic (EM) waves depends on how many electrons are captured by the unstable EM waves. We discuss that our analytic results are compared with the experimental results and our numerical simulation for the trapped ratio with $(\gamma/\gamma_{b0})^n$. Here, n is the integer, γ the final electron beam energy and γ_{b0} the initial beam energy, respectively. Finally, it is shown that the Cherenkov mechanism is dominant for the microwave amplication at a low current, whereas the stimulated Raman scattering combined with the Cherenkov effect may occur and the parametric instability occurring between space-charge waves on a relativistic beam and TM modes in a waveguide is responsible for the Doppler up-shift of the real frequency when the current becomes very high.

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Design of a 30 GHz Bragg reflector for a Raman FEL

P. Zambon
University of Twente
Department of Applied Physics
P.O. Box 217
7500 AE Enschede, The Netherlands
and
P.J.M. van der Slot
Nederlands Centrum voor Laser Research B. V.
P.O. Box 2662
7500 CR Enschede, The Netherlands

We describe the design of a Bragg reflector for the Raman FEL situated at the University of Twente [1]. A numerical code based on the coupled mode equations for the cylindrical waveguide Bragg structure [2,3] was used to calculate the properties of the mirror at a Bragg frequency of 30 GHz. It is shown that applying a Hamming window to the corrugation height improves the mode purity. The results of the calculations are confronted with experimental measurements.

A nonlinear Raman FEL model [4], modified for an oscillation configuration is used to investigate the influence of the Bragg reflector on the FEL interaction. The electron pulse has a duration of 100 ns and only allows for 6 to 7 round-trips of the radiation in the cavity. We will discuss the build-up of the radiation in the cavity.

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PECULIARITIES OF THE HARMONIC GENERATION IN THE SYSTEM OF THE IDENTICAL UNDULATORS

E.G.Bessonov

Lebedev Phys. Inst. of the Russian Academy of Sciences, Moscow, Russia

The system of two situated in sequence undulators is named the Undulator Klystron (UK) [1]. The modification of the UK with the dispersive magnets is named Optical Klystron (OK) [2]. In general case UK consist of $N_0 > 2$ undulators that are turned one relatively another on some angles and have different periods, magnetic fields and the number of the periods [3-5].

In this paper the attention is paid on the possibility of suppressing the low Undulator Radiation (UR) harmonics and increasing of some definite high UR harmonics in the UK consisting of even number of the plane identical undulators with high deflecting parameters. The idea of the intensification of some definite UR harmonics in the UK is next one. The nonharmonical wavepackets of the UR emitted by the particle in any undulator of the UK is the sum of the same length harmonical wavepackets. That is why the choice of the distance between the wavepackets multiple to the wavelength of the definite high harmonic and nearly equal to the half wavelength of the first harmonic will permit to intensify the high harmonic of the UR of the UK. For this purpose it is possible to choose definite distances between undulators of the UK and definite deflecting parameters of the undulators. In this case undulators of the UK may be turned one relatively another at the angle π. Also the general case, when UK consist of as identical as different undulators situated on definite distances is examined. The spectral distribution of the spontaneous radiation, the gain of the Free-Electron Laser (FEL) and the possible performance of the UK are investigated. This work supplement and generalize the work [6], where the UK consisting of different undulators was considered.

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SIMULATIONS OF NON-IMMERSED CATHODE FEL EXPERIMENTS WITH HELICAL WIGGLER AND SOLENOID

J.GARDELLE, Ph GOUARD*, J.LABROUCHE, P.LE TAILLANDIER

C.E.A./C.E.S.T.A., PO Box 2, 33114 LE BARP, (France)
*C.E.L./T.E.N., PO Box 27, 94190 VILLENEUVE-SAINT-GEORGES, (France)

Free Electron Lasers experiments using circulary polarized wiggler and axial guiding magnetic fields need 3D simulation codes to improve calculations obtained from linear theory. Efficiency and operating parameters are studied with the ARACHNEE code[1] whereas effects of an actual electron beam (i.e. initial conditions) on FEL interaction are investigated with the SOLITUDE code; this latest allows us to have a descriptive approach of beam quality. Another code, ELECTRA, has been especially written to determine the best conditions of transport in the experiment and to study propagation in the LELIA induction accelerator[2]. We have coupled these two codes to get a quantitative and more comprehensive approach of FEL output power reduction due to electron beam quality: emittance, alignment, divergence...

After a description of these two codes, we shall give first their general results, paying a particular attention to initial conditions at wiggler entrance for an immersed configuration. We show that beam quality requirements are not so drastic for ONDINE-like parameters in this case. After that, we shall present examples of electron trajectories and FEL amplifier simulations for the real ONDINE1 experimental parameters[3]. The low gain and poor reproductibility obtained for this first experiment can be explained quantitatively by looking at the great axial energy dispersion at the wiggler entrance. This one coming from the very important axial magnetic field gradient at this location, as the coupling between ELECTRA and SOLITUDE show.

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Microwave Systems for Millimeter and Submillimeter Free Electron Masers

G.G.Denisov

Institute of Applied Physics, Nizhny Novgorod, Russia

New types of microwave systems for free electron masers (FEM) are discussed. The systems were used in recent experiments with FEM or are planned for use in various projects.

The following general requirements has to be met by a microwave system for FEM. It has to: provide phase and group velocity of the operating wave necessary for frequency up-conversion and high efficiency and, simultaneously, an acceptable (low) level of ohmic and diffraction losses; exclude self-excitation of undesirable parasitic modes; separate electron and wave beams after interaction and organize output of radiation. A complete scheme of a high-power FEM depending strongly on a microwave system has to be reliable, i.e., stable to small changes of electron beam parameters (energy, current, profile of density, etc.).

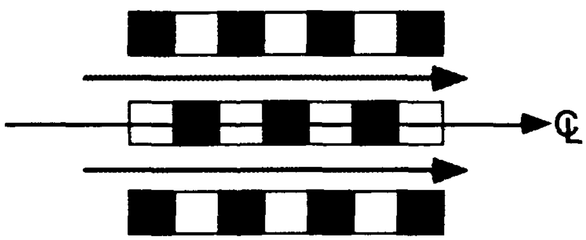
As components for FEM microwave systems, one can use pieces of oversized metallic waveguides and quasi-optical mirrors. Low level of ohmic losses implies TMon (or analogous ones) operating modes in circular and plane waveguides or hybrid modes in corrugated waveguides. To provide selective feedback in oversized waveguides, Bragg reflectors or reflection from cavities with an auxiliary wave coupled to the operating one can be used. A lot of possibilities in forming microwave systems is given by the phenomenon of image multiplication in oversized waveguides.

Results of calculations and experimental investigations of three systems for specific FEMs are presented: 1) Bragg resonator for a high-current millimeter-wave cyclotron autoresonance maser (CARM); 2) Microwave system consisting of a corrugated rectangular waveguide, separation system for electron and wave beams, adjustable reflectors, for FEM at the FOM Institute; 3) Microwave system based on an open elliptical waveguide for submillimeter CARM for plasma diagnostic.

THE COAXIAL HYBRID IRON (CHI) WIGGLER*

Robert H. Jackson, Henry P. Freund,† and Dean E. Pershing§
Code 6840, Vacuum Electronics Branch
Naval Research Laboratory, Washington, D.C. 20375-5347
Phone: (202) 767-6656; FAX: (202) 767-1280

One approach under investigation to enhance the performance of FELs is small period magnetic wigglers ($\lambda_w \leq 5$mm). Development of a practical high-field micro-wiggler design would benefit FEL performance by reducing size, and lowering voltage and shielding requirements or by increasing the frequency range accessible with existing accelerators. A micro-wiggler design has been developed at NRL which is scalable to small λ_w with high field amplitude, has high beam current acceptance, and focusing in and perpendicular to the wiggle plane. The wiggler design consists of a coaxial arrangement of alternating ferromagnetic and non-ferromagnetic rings with the central portion shifted by $\lambda_w/2$ shown below. The entire arrangement is immersed in a solenoidal field resulting in a periodic radial magnetic field and a reduced axial field with a low amplitude ripple. FEL configurations using this wiggler design have the potential for high power, high frequency coherent generation in relatively compact systems. Analytic and calculated characteristics of this wiggler configuration will be presented along with performance estimates for a conceptual FEL design.



* Work sponsored by the Office of Naval Research.

†Permanent Address: Science Applications International Corp., McLean, VA 22102, USA.

§Permanent address: Mission Research Corp., Newington, VA 22122, USA.

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Plane electromagnetic undulators of the P.N.Lebedev Physical Institute

V.A.Papadichev, V.S.Vysotsky, V.N.Tsikhon, S.G.Deryagin, V.T.Eremichev,
V.A.Bogachenkov, O.A.Smith, S.M.Zakharov
P.N.Lebedev Physical Institute
117924 Moscow, Russia

Electromagnetic plane undulators of various types were designed and studied experimentally at the P.N.Lebedev Physical Institute. They are to be used in an RF-linac based FEL project now under development.

The first undulator has a 4 8 mm period and two sets of annular iron yokes for positive and negative poles, the yokes being placed on opposite sides of the undulator axis. Such a design simplifies undulator windings, which are simple coils around each set of yokes. Results of magnetic field measurements are given and discussed.

The second undulator has superconducting coils and iron poles. Its period is 8 mm. Various pole shapes have been tried with a maximum field of about 1 T for trapezoidal poles.

The third type of undulator is a pulsed one with laminated iron. Its winding is made of 0.2 mm copper tape and is of snake-like form. The undulator period is 3 mm. Results of field measurements are presented.

26Thu

An Undulator for FELICITA I*

T. Schmidt, F. Brinker, D. Nölle
Institute for Acceleratorphysics and Synchrotronradiation
University of Dortmund
P.O. Box 500 500
4600 Dortmund 50, FRG
Fax: (FRG) 231-755-5374
email: thomas at marvin.physik.uni-dortmund.de

FELCITA I is the first FEL experiment at the storage ring DELTA of the University of Dortmund funded till October'92. The device is designed for the wavelength regime between 400–200 nm. It will provide two operation modes. It can either be run as an optical klystron but also as a conventional FEL.

The design of the special "two in one" electromagnetic undulator magnet for this FEL will be presented here. The undulator can be switched from one mode into the other simply by reclamping the coils. It consits of 17 periods of 25 cm length plus 2 matching periods. With a gap of 50 mm the field amplitudes are 0.09 T in the undulator sections and 0.7 T for operation with dispersive section. The assembly of the undulator will be completed at the end of this year.

*This work is supported by the Bundesministerium für Forschung und Technologie under contract 05 3PEAAI 0

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OPTICAL ALIGNEMENT AND BEAM EXTRACTION AT THE CLIO INFRARED LASER FACILITY

J. M. Berset , F. Glotin, R. Prazeres, J. M. Ortega

LURE, bat. 209d, Univ. Paris-Sud, Orsay, 91405 - FRANCE

ABSTRACT:

The RF linac based CLIO FEL has lased in the spectral range 2.5 to 15.5 μm and the peak power is several MW in 1 to 10 ps pulses(1). Beam extraction realised by an intracavity outcoupling plate oriented at 60° to the incident beam. Various materials have been tested. The best, to-date, is ZnSe. This configuration preserves the FEL mode quality. However, it produces 2 sets of reflections . One of these is used in the accelerator room to monitor the FEL & accelerator adjustments; the second is sent to users through a 40 m long beam line purged of H_2O and CO_2. However, in this configuration the successive reflections on the plate produce 2 pulses, instead of 1, separated by a time delay of at least 10 ps. Therefore, we are installing a hole coupling configuration that will also allow the spectral range to be extended toward longer wavelengths.

A comparative analysis will be made of the above methods.

(1) F. Glotin, R. Prazeres, J. M. Berset, R. Chaput, D. Jaroszynski, J.M. Ortega - This conference

THE SLAC SOFT X-RAY HIGH POWER FEL*

C. Pellegrini, J. Rosenzweig, G. Travish
UCLA Department of Physics, Los Angeles, California 90024
K. Bane, R. Boyce, G. Loew, P. Morton, H.-D. Nuhn, J. Paterson, P. Pianetta, T. Raubenheimer, J. Seeman, R. Tatchyn, V. Vylet, H. Winick
Stanford Synchrotron Radiation Laboratory, Stanford, California
K. Bane, T. Raubenheimer, J. Seeman
Stanford Linear Accelerator Center, Stanford, California
K. Halbach, K.-J. Kim, M. Xie
Lawrence Berkeley Laboratory, Berkeley California
D. Prosnitz, T. Scharlemann
Lawrence Livermore National Laboratory

ABSTRACT

We discuss the design and performance of a 2 to 4nm FEL operating in Self Amplified Spontaneous Emission (SASE), using a photoinjector to produce the electron beam, and the SLAC linac to accelerate it to an energy of about 7 GeV. Longitudinal bunch compression is used to increase ten fold the peak current to 2.5 kA, while reducing the bunch length to the subpicosecond range. The FEL gain length is about 6 m, and the saturation length is about 60m.The saturated output power of the FEL is in the multi-gigawatt range, producing about 10^{14} coherent photons with a bandwidth of about 0.1% rms, in a radiation pulse of several millijoules.

Micro Cherenkov FEL Driven by FEA

K. Mima, [a]T.Taguchi, [b]N.Ohigashi, [c]Y.Tasunawaki, [d]M.Shiho, [e]S.Kuruma, R.Imashioya and S. Nakai

Institute of Laser Engineering, Osaka University, Osaka, Japan

a) Faculty if Engineering, setsunan Univ., Osaka, Japan

b) Faculty of Engineering, Kansai Univ., Osaka, Japan

c) Faculty of Engineering, Osaka Industry Univ., Osaka, Japan

d) JAERI, Nakamachi, Ibaraki, 311-01, Japan

e)Institute for Laser Technology, Osaka, Japan

It is possible to reduce scale and wavelength of FEL simultaneously by using micro-scale electron beams from a field emission array(FEA). A few emission processes can be applied for the FEA FEL, which are Cherenkov emission, Smith-Percell emission, and so on. In this paper, we present a design of a micro Cherenkov FEL driven by a FEA and the present status of the experimental set-up.

One of the key issues for the FEA FEL is how to confine an electron beam within a few μm diameter. The FEL wavelength will not be shorter than the electron beam diameter. The numerical analysis of the electron trajectory for a 0.2μm diameter cathode show that electron beam can be confined within 2μm diameter with 1 Tesla axial magnetic field.

The 2μm diameter beam is accelerated electrostatically up to 100kev and injected into a corrugated wall wave-guide on a high refractive index dielectric waveguide for smith-Percell or Cherenkov FELs. In this case, the lasing wavelength can be shorter than 10μm.

Since the FEA FEL is an array of micro-FELs, the phase-lock of radiations in the FEL array is important form the stand point of the spatial(transverse) coherence of the laser light. In this presentation, we also discuss the phase relation between neighboring micro-FEL radiations.

FREE-PROTON LASERS BASED ON THE HIGH ENERGY ACCELERATORS AS THE HIGH POWER, HIGH EFFICIENCY CM-TO X-RAY MACHINE

E.G.Bessonov

Lebedev Phys. Inst. of the Russian Academy of Sciences, Moscow, Russia

Protons and more heavy ions emit undulator radiation (UR) as effectively as electrons when they are moving through the undulator along the same traectory with the same relative energy $\gamma = \varepsilon/mc^2$. In that case the value of the undulator magnetic field is proportional to the particle mass (deflecting parameters of particles are equal one). For the effective generation of the UR the value of the undulator magnetic field must be of the order of optimal one $H \simeq H_c \simeq 2\pi mc^2/e\lambda_u$, where λ_u is the undulator period [1]. Coefficient $2\pi mc^2/e$ is $\simeq 1.07 \cdot 10^4 Gs \cdot cm$ and $1.97 \cdot 10^7 Gs \cdot cm$ for electrons and protons correspondingly. For protons minimal $\lambda_u|_{H \simeq H_c} \simeq 1m$ is defined by the maximum magnetic field intensity $\sim 10^5$Gs. When the undulator period $\lambda_u \simeq 1m$ and $\gamma \simeq 10^3$ ($\varepsilon \simeq 1TeV$) the UR is in the optical wavelength region: $\lambda \simeq \lambda_u/2\gamma^2 \simeq 5.10^{-5}cm$. The energy of the proton beams at the same γ-factor and the same number of particles N is ~ 2000 times more then the energy of the electron beams. It exceeds now ($\varepsilon = 1TeV, N = 10^{13}$) the value $N\varepsilon = 1MJ$. In the UNK (3TeV), LHC (10TeV) and SSC (20TeV) projects of storage rings it will reach $\sim 100 \div 500MJ$. At LHC as protons as heavy ions will be stored up to fully stripped ${}_{82}Pb^{207}$ [2]. The average current of the CERN storage ring ISR had reached $50A$ at the energy $\varepsilon_p \simeq 31.5GeV$. It is possible to compress the proton beams to the longitudinal dimensions $\sim 1 \div 10^2$cm [3,4]. It means that the utilization of the undulators with the number of the periods $K > 10^2$, $\lambda_u \sim 1m$ and proton beams with the bunch current $i_p > 10^2 A$ and the energy $\varepsilon > 0.1GeV$ will permit to construct Free-Proton Laser (FPL) [5] and to transform the energy of the particles in the cm to optical wavelength region. Utilization of the micro bunched proton beams with the period equal IR or optical wavelength λ will result in the effective generation of the coherent UR on higher harmonics in the IR to X-ray wavelength region [6,7]. In the case of SSC and LHC there is essential synchrotron radiation of protons and high degree striped ions that leads to the decreasing of the beam emittanses and hence to more unique quality of the ion beams. The requirements to the proton and heavy ion storage rings of the FPLs are similar to the heavy ion inertial fusion one [8,9]. In this work some theoretical aspects and possible technical realizations of the FPLs based on the high and superhigh proton synchrotrons are discussed.

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27Fri

Development of a Compact Laser Undulator Soft X-Ray Source

J. Chen, M. Fujita, K. Imasaki, and C. Yamanaka
Institute for Laser Technology, 2-6 Yamada-oka, Suita, Osaka
M. Asakawa, S. Nakai
Institute of Laser Engineering, 2-6 Yamada-oka, Suita, Osaka

Based on a compact RF-linac with nominal energy 6-10MeV and a high power YAG:Nd Laser, a laser undulator[1-3] experiment has been proposed in ILT/ILE. The mechanism is Thomson backscattering, essentially the same as in conventional synchrotron sources except the replacement of magnetic undulator by a high intensity laser. Since the electron beam micropulses must be synchronized with laser pulses at the focal point,by the status of our preliminary system,the overall duty factor is $D=1.3\times10^{-8}$ which results an average spectral brightness of soft x-ray radiation about 2.0×10^{9} (*) with a photon energy of 1KeV(12.3 Å).

For enhancing the duty factor in our upgrade system to satisfy the requirement of application in lithography, we propose to substitute the pulsed YAG:Nd laser by a CW Ti:sapphire laser which is used to excite an ultralow loss cavity with reflectivities higher than 0.999995 and total mirror loss (transmission plus scatter and absorption) below 8×10^{-5} where the small input power can be accumulated to the order of tens of megawatts. And we also propose to design a compact electron storage ring with the energy of 10-20MeV and size of ϕ 2m using the existing RF-Linac as its injector. By trading off the parameters, we estimate that the average spectral brightness of this new laser undulator system will get the order of 10^{15}-10^{18} (*) in soft x-ray region by a high duty of 1×10^{-2} which already touches on the photon yield level of LBL 1-2GeV synchrotron source in USA or Spring-8(GeV) in Japan.

It is predicted that the life time of low energy electron storage ring and the accumulation of optical energy in a ultralow loss resonator will be the main technical challenges. In this paper, we shall discuss some about the Touschek effect which mainly determines the life time of the stored beam current in an electron storage ring with a low beam energy less than 100MeV, and the methode of power injection between ultrahigh reflectivity mirrors. Meanwhile the schematic diagram of our laser undulator system will be presented which will become a compact soft x-ray source used for 0.25 μm scale ULSI fine processing.

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(*)photons/sec.mm^2.mrad^2.0.1%Bandwidth

An Accelerator/Wiggler for High Efficiency FEL Operation

J.W. Lewellen, J.F. Schmerge, J. Harris, J. Feinstein, R.H. Pantell

McCullough 310
Electrical Engineering Department
Stanford University
Stanford CA 94305, USA

A possible approach to high efficiency FEL operation is to combine a microwave linear accelerator and magnetic wiggler into a single structure. As the electrons lose energy to the radiation at the FEL oscillation wavelength (e.g. infrared), energy is replaced by the microwave linac. The electron beam acts as a catalyst for the conversion of microwave power to infrared power. Several advantages to the accelerator/wiggler are: it is possible to obtain high conversion efficiency in a short length; small-signal gain reduction can be avoided; power extraction may be increased by increasing length; there is little detrapping; and electron beam energy out of the wiggler is relatively monochromatic, permitting efficient energy recovery.

A six-period, full-scale model of the accelerator/wiggler has been fabricated to check the computer simulations for both microwave and magnetic properties; to test the manufacturing techniques; and to design a microwave matching section. Measurements on this model indicate that the predicted Q is accurate, that there is ≈ 1.5% error in the predicted resonant frequency, that dimensional tolerances could be maintained with electrical discharge machining (EDM), and that it is difficult to achieve critical coupling to the structure.

The design and performance characteristics of an accelerator/wiggler will be described, as well as some of the practical considerations in fabrication and testing.

A STUDY OF LINEWIDTH, NOISE AND FLUCTUATIONS IN A FEL OPERATING IN SASE

P.Pierini, N.Piovella, L.DeSalvo Souza and R.Bonifacio

Università di Milano and INFN Sezione di Milano, Via Celoria 16, 20133 Milano, Italy

C.Pellegrini

Physics Dept., University of California Los Angeles, USA

We study the evolution of the FEL radiation intensity and spectrum starting from noise in the electron beam longitudinal distribution. We consider the case when the bunch is much longer or of the order of the cooperation length L_c. In the limit of an undulator shorter than one gain length L_g, we recover the spontaneous radiation spectrum, as an envelope of a noise spectrum. In the limit of an undulator length corresponding to many gain lengths, we show that there is a spectral narrowing of the linewidth to a value of the order of the FEL parameter ρ, up to saturation, followed by a broadening. For long undulators the spectral characteristics are different when the bunch length, L_b, is much larger than the cooperation length or of the order of a few times L_c. The field evolution is dominated by slippage effects in both cases, and shows the presence of superradiant spikes. We present analytical and numerical results.

A SOLITARY WAVE THEORY FOR SPIKING PULSES EMITTED BY A RAMAN FREE ELECTRON LASER

Li-Yi Lin and T.C. Marshall
Department of Applied Physics
Columbia University, New York City 10027

We have extended a solitary wave theory [1] for high power spike pulses [2,3], emitted from a FEL by including the space charge wave and treating the radiation field in two dimensions so as to allow for the waveguide. In this manner we derive the "collective variables" equations which will correctly describe the physics of the Columbia Raman FEL. The refractive index of the electron beam in the nonlinear regime and the saturation intensity of the radiation field is obtained from a WKB theory. It is shown that the nonlinear behavior of the radiation field can be modeled by the Ginzburg-Landau equation [1] using coefficients which are obtained from the collective variables analysis. The GL equation has solitary wave solutions that have a spiking character, lasting a few hundred psec. We program the GL equation to study the spike evolution from different initial conditions: an isolated spike resembles the analytic solitary wave solution of the GL equation and is compared to those found experimentally. We have also examined how spikes grow from "noisy" initial conditions in the signal field.

Research supported by the ONR

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UP FREQUENCY CONVERSION IN A TWO RESONANT WAVES HIGH GAIN FEL AMPLIFIER

N. Piovella, V. Petrillo, C. Maroli and R. Bonifacio

Dipartimento di Fisica dell'Università di Milano
Via Celoria 16, 20133 Milano - Italy

Superradiance and bunching are studied in a high gain FEL in vacuum and in a waveguide, taking into account the existence of two different resonant frequencies, ω_1 and ω_2. A set of partial differential equations has been written, assuming the existence of two waves with positive and negative slippage, respectively. The interaction of these waves with the electron medium is studied in the linear and non-linear high gain regime; in particular we demonstrate the following novel result: if one injects a small signal at the lower frequency ω_2, one obtains strong signal and bunching at the upper frequency ω_1, provided that the ratio ω_1/ω_2 is an integer number, which can be arbitrarily large. This fact suggests a new method for generating short wavelength radiation.

TUNABLE, SHORT PULSE HARD X-RAYS FROM A COMPACT LASER SYNCHROTRON SOURCE*

Phillip Sprangle, A. Ting, E. Esarey, and A. Fisher

Plasma Physics Division
Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5346

A laser synchrotron source (LSS) is proposed as a means of generating tunable, narrow bandwidth, ultra-short pulses of hard x-rays.[1] The LSS is based on the Thomson backscattering of intense laser radiation from a counterstreaming electron beam. Advances in both compact ultra-intense solid-state lasers and high brightness electron accelerators make the LSS a potentially attractive compact source of high brightness pulsed x-rays, particularly at photon energies beyond ~ 30 keV. For an electron beam energy of 72 MeV and laser wavelength of 1 μm x-rays at 0.12 Å (100 keV) can be generated. Using present day technology, the LSS can generate picosecond pulses of x-rays consisting of > 10^8 photons/pulse and tunable photon energies from 50-1200 keV. The spectral flux, brightness, bandwidth and pulse structure are analyzed and a comparison with conventional storage ring sources is made.

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